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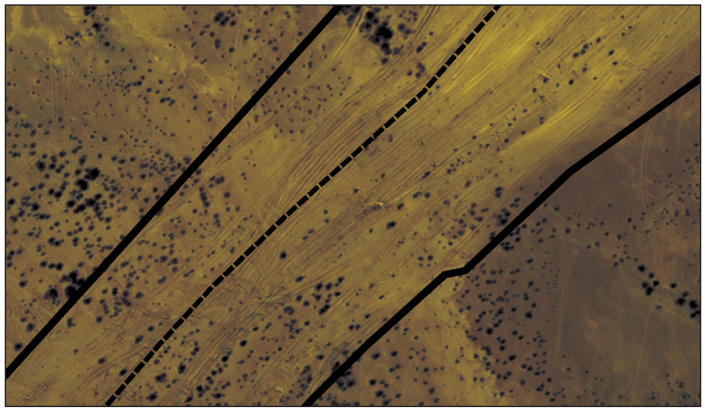
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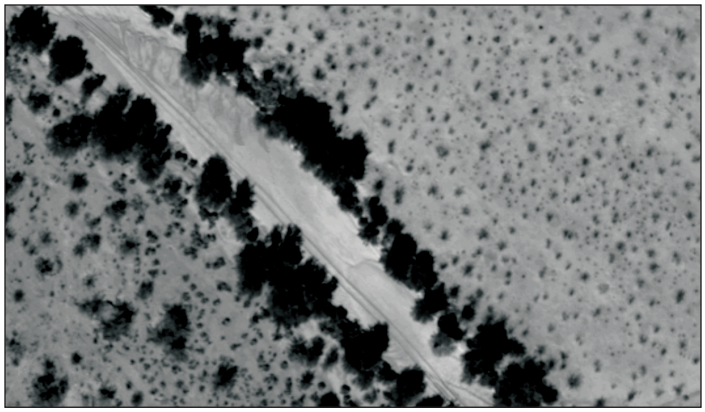
Inventory and Assessment of Undesignated Vehicle Routes on Department of the Interior Lands in the SBI*net* Ajo-1 Project Area and Vicinity, Southwestern Arizona

August 2014

Natural Resource Technical Report NPS/ORPI/NRTR—2014/900







ON THE COVER

Clockwise, from left: Class 2 undesignated vehicle route (UVR) near Cholla Pass in the Bates Mountains, Organ Pipe Cactus NM; Class 4 UVR in the Growler Valley, Cabeza Prieta National Wildlife Refuge, from aerial photograph; Aerial view of Class 3–Wash UVR.

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Fort Collins, Colorado

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Abstract

Department of the Interior lands along the southwestern Arizona border with Mexico constitute a significant portion of protected public lands in the Sonoran Desert. Regardless of jurisdiction, these lands are currently experiencing conservation challenges due to recent increases in border-related activities. Human disturbance, in the form of cross-border traffic and law-enforcement interdiction efforts, was identified in the U.S. Fish and Wildlife Service (FWS)'s biological opinion on the U.S. Border Patrol's Secure Border Initiative Ajo-1 Tower Project (SBI*net* Ajo-1) (FWS 2009) as the most significant current source of disturbance to the U.S. population of the Sonoran pronghorn (*Antilocapra americana sonoriensis*). Sonoran pronghorn are federally listed as endangered with extinction under the Endangered Species Act, and the current range of this endangered population in the U.S. lies within the SBI*net* Ajo-1 project area and vicinity.

In 2011, the National Park Service (NPS) entered into an interagency agreement with the Department of Homeland Security (DHS) to map and assess undesignated vehicle routes (UVRs) on Cabeza Prieta National Wildlife Refuge (CPNWR), Organ Pipe Cactus National Monument (OPCNM), and Bureau of Land Management (BLM) lands within or in close proximity to the SBI*net* Ajo-1 project area. UVRs were manually mapped in a geographic information system using high-resolution aerial photography from 2008 and 2010 and then assigned to a class system that describes relative rates of use and environmental impact, ranging from single-use tracks to well-used routes. These data were used to depict areas of concentrated vehicle use, provide information for ongoing Sonoran pronghorn recovery efforts, and form the foundation for planned habitat restoration activities.

Approximately 9,327 miles (15,010 km) of UVRs were documented in the project area and assigned to one of four condition classes indicating level of disturbance (1=least disturbed, 4=most disturbed). Ninety-two percent of UVR mileage was categorized as Class 1 (usually single-use vehicle tracks), 3.1% was Class 2, 4.7% was Class 3 and 0.2% was Class 4. For UVR classes 1, 2, 3, and 4 respectively, the average UVR widths were estimated to be 7.2 feet (2.2 m, range 4.9–8.9 ft/1.5–2.7 m), 7.9 feet (2.4 m, range 6.2–10.1 ft/1.9–3.1 m), 8.4 feet (2.6 m, range 5.9–11.1 ft/1.8–3.4 m) and 148.3 feet (45.2 m, range 26.2–482.2 ft/8–147 m). The Growler Valley, which is shared between CPNWR and OPCNM, had the highest UVR density in the project area.

An increase of UVR mileage was seen from 2008 to 2010, and expansion continued after 2010. This continued expansion of UVRs is of utmost concern to land managers responsible for Sonoran pronghorn recovery. The NPS is currently developing a programmatic environmental assessment describing a wide range of restoration activities that may be used to restore UVR-impacted areas. Restoration activities are anticipated to commence in earnest during 2014.

**The term, "undesignated vehicle route" replaces "unauthorized vehicle route," the original term used in FWS (2009).*

Acronyms, Abbreviations, and Definitions

ac	acres
BO	Biological Opinion, a legally binding document that expresses the opinion of the U.S. Fish and Wildlife Service on whether a proposed federal action is or is not likely to jeopardize a federally threatened or endangered species
BLM	Bureau of Land Management
CBP	U.S. Customs and Border Protection
cm	centimeters
CPNWR	Cabeza Prieta National Wildlife Refuge
DEM	digital elevation model
digitize	to draw or put into digital form
DHS	Department of Homeland Security
DOI	Department of the Interior
EIS	Environmental Impact Statement, a document that describes the impacts on the environment as a result of a proposed action
F	Fahrenheit
false negative rate	A type of error rate, defined as the frequency with which features are missed or go undetected that belong to the group assignment (also called Type II error, omission error)
false positive rate	A type of error rate, defined as the frequency with which features that do not belong to the group assignment are included (also called Type I error, commission error)
ft	feet
FWS	U.S. Fish and Wildlife Service
GIS	Geographic Information System
ha	hectares
km	kilometers
kmh	kilometers per hour
m	meters
mi	miles
mm	millimeters
mph	miles per hour
NAIP	National Agriculture Imagery Program
NM	national monument
NPS	National Park Service
NWR	national wildlife refuge
OPCNM	Organ Pipe Cactus National Monument
SBI*net* Ajo-1	Secure Border Initiative Ajo-1 Tower Project, a network of surveillance towers that monitor human activity
st dev	standard deviation
UVR	Undesignated vehicle route—replaces "unauthorized vehicle route," which was the original term used in FWS (2009).

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1 Introduction

1.1 Project foundation

In 2009, the U.S. Fish and Wildlife Service (FWS) issued a biological opinion (BO) on the effects of the U.S. Customs and Border Protection's (CBP) Secure Border Initiative Ajo-1 Tower Project (SBI*net* Ajo-1) on federally endangered species, including the Sonoran pronghorn (*Antilocapra americana sonoriensis*) (FWS 2009). The SBI*net* Ajo-1 project established a network of high-tech surveillance towers within the current range of the U.S. population of endangered Sonoran pronghorn. Department of Interior (DOI) lands affected by this project include Cabeza Prieta National Wildlife Refuge (CPNWR), Organ Pipe Cactus National Monument (OPCNM), and the Bureau of Land Management's (BLM's) Ajo block. The purpose of this tower network is to detect and monitor illegal cross-border activity, and in so doing, provide CBP an enhanced opportunity to interdict such activity.

Human disturbance, in the form of cross-border traffic and law-enforcement interdiction efforts, was identified in the BO as the most significant current source of disturbance to Sonoran pronghorn in the United States. Sonoran pronghorn are susceptible to human disturbances and experience stress responses and potential subsequent increases in energetic expenditures as a result of such disturbance. Pronghorn responses to human presence or motorized vehicle traffic include increased heart rates, interruption of foraging, running from disturbances, or relocation out of preferred habitats. Range abandonment has been documented when disturbance rates exceed pronghorn tolerance for human disturbance, including noise (FWS 2009).

This susceptibility to disturbance is of great concern to managers, as overall reproductive and survival rates for the pronghorn population may be lowered as a result (FWS 2009). The BO developed several offsetting measures relative to impacts on Sonoran pronghorn, including the need to:

> . . . assess and map the number and extent of unauthorized, repetitively used UVRs [unauthorized vehicle routes] in Sonoran pronghorn habitat or potential habitat on CPNWR, OPCNM, and BLM lands within or in close proximity to the Ajo-1 project area. This assessment will locate, record, and map UVR occurrences throughout pronghorn habitat within the project area. The assessment will also quantify UVR dimensions and severity as well as determine restoration potential and needs (FWS 2009).

In 2011, the National Park Service (NPS) entered into an interagency agreement with the Department of Homeland Security (DHS) to map and assess UVRs on CPNWR, OPCNM, and BLM lands within or in close proximity to the SBI*net* Ajo-1 project area. This report summarizes the results of the UVR assessment. Our primary goal in this inventory was to document the location of repeatedly used UVRs to better understand vehicle traffic patterns, traffic volume, and extent of environmental damage, in order to inform ongoing Sonoran pronghorn management and recovery efforts and help determine areas suitable for habitat restoration activities.

Per FWS (2009), habitat restoration proposals will be developed by each Department of the Interior (DOI) agency and submitted for review and approval by a DOI steering committee. Approved proposals that receive funding as an offsetting measure under FWS (2009) require CBP concurrence prior to implementation. Finally, a reassessment of UVRs is called for after implementation of restoration activities to evaluate the effectiveness of SBI*net* Ajo-1 offsetting measures.

1.2 Project area

The UVR roads assessment project area includes all of CPNWR, all of OPCNM, and a portion of the BLM–Lower Sonoran Field Area known as the Ajo Block, which lies south of Ajo, Arizona, and west of Arizona state highway 85 (Figure 1-1). Collectively, the project area constitutes a significant portion of the Sonoran pronghorn's current U.S. range in the wild. The remaining portion of the pronghorn's range occurs on Department of Defense (DOD) managed lands north of the project area. These DOD lands were not assessed during this project. A second experimental population of Sonoran pronghorn,

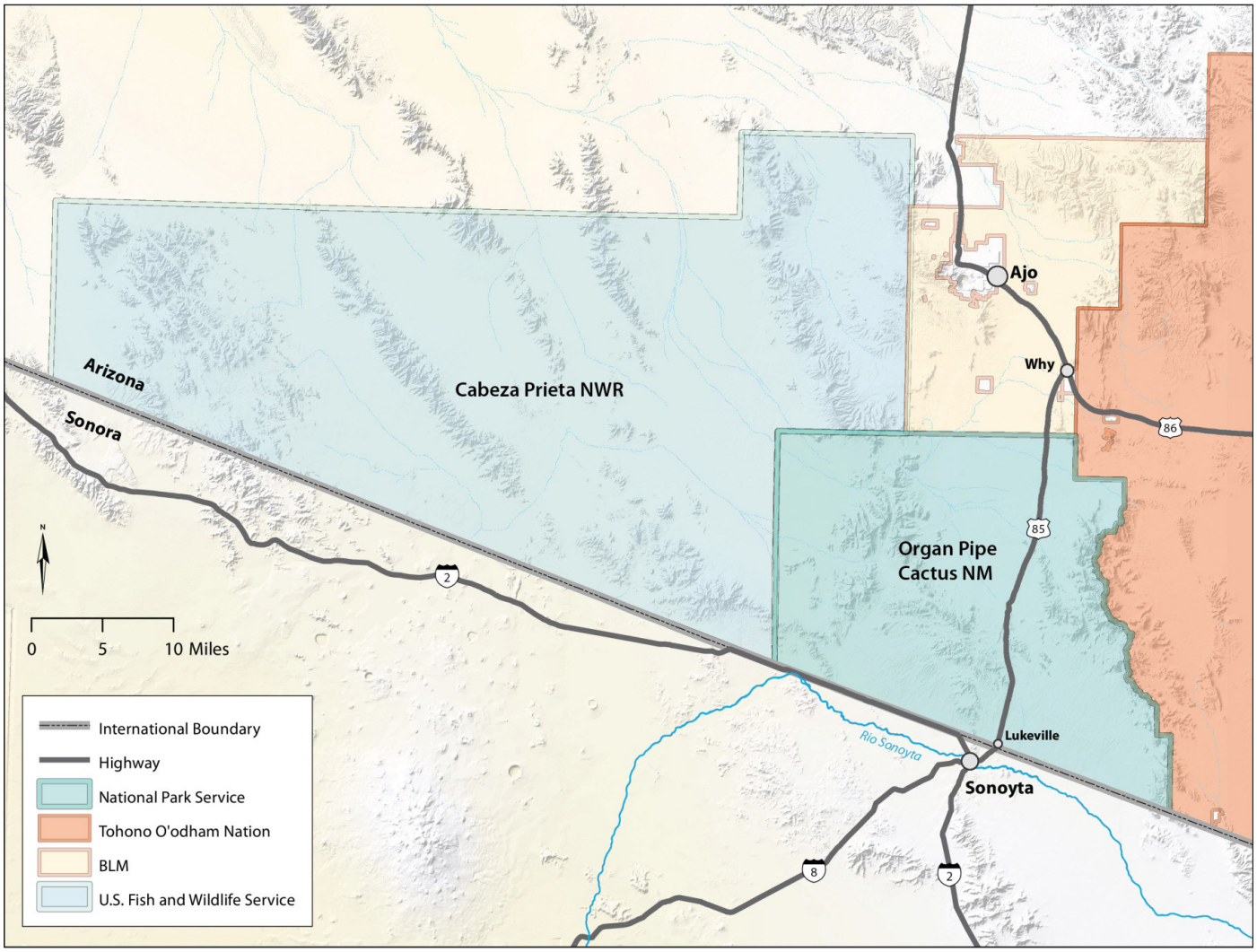


Figure 1-1. The project area: Federally managed lands along a portion of the southwestern Arizona border, including a portion of the BLM Ajo Block.

listed as 10j under the Endangered Species Act, is located on Kofa National Wildlife Refuge, which lies beyond the area affected, directly or indirectly, by SBI*net* Ajo-1.

FWS (2009) specifies that priority consideration "to close and/or restore UVR occurrences" will be given to

> those portions of CPNWR, OPCNM, and BLM lands influenced by the Ajo-1 SBI*net* project where pronghorn habitat or potential habitat occurs. DOI land management agencies will prioritize UVR impacted areas for closure and restoration based on each area's relative importance to Sonoran pronghorn and by taking into account specific knowledge of each UVR impacted area.

1.2.1 Biogeography

This report's project area includes both existing and potential Sonoran pronghorn habitat, and extends over 1.3 million acres and 83 miles (4%) of the international boundary between the U.S. and Mexico (Figure 1-1). This area lies within the Basin and Range geologic province, which consists of northwest–southeast trending, isolated mountain ranges separated by broad alluvial valley floors. Plant communities are characterized by the Arizona Upland and Lower Colorado River Valley subdivisions of the wider Sonoran Desert biotic community (Shreve 1964). The Arizona Upland subdivision contains extensive stands of columnar cactus; there are also small, non-desert plant communities at elevations >3,500 ft (1,067 m)—consisting, for instance, of Arizona juniper (*Juniperus*

arizonica), Sonoran scrub oak (*Quercus turbinella*), and Arizona rosewood (*Vauquelinia californica*) woodlands).

The Lower Colorado River Valley subdivision consists of broad valley floors occupied mainly by creosote (*Larrea tridentata*) and bursage (*Ambrosia* species). Precipitation generally declines along an east–west gradient, with most low-elevation areas receiving 4–10 inches (100–250 mm) of rain per year and high-elevation eastern mountains receiving closer to 12 inches (300 mm) of rain per year. Most precipitation occurs during two main seasons: infrequent, intense rain during the summer monsoon, and longer-lasting, more widespread rainfall driven by Pacific storm systems in the winter. Summertime daytime temperatures often exceed 100°F (38°C) and wintertime daytime temperatures usually range from 60 to 80°F (15–27°C). Freezing nights are uncommon in most of the project area, generally occurring less than one dozen (12) times per year (NPS 2012).

1.2.2 Cabeza Prieta National Wildlife Refuge

First designated as a game refuge for the desert bighorn sheep in 1939, the purpose of CPNWR was expanded in the National Wildlife Refuge System Improvement Act of 1997 to include the conservation of fish, wildlife, and plant resources and recreational use compatible with refuge missions (FWS 2006). CPNWR covers a vast area (860,010 ac/348,033 ha) of the Sonoran Desert and is the third-largest wildlife refuge in the contiguous U.S. CPNWR constitutes 69% of the project area, has approximately 450 miles (724 km) of public and/or administrative roads, and shares 56 miles (90 km) of border with Mexico.

Notably, the refuge contains a portion of the "El Camino del Diablo" (Devil's Highway), a route established in the 1500s by the Spanish that later served as a migration route during the California gold rush of 1849. Beyond the refuge to the east, the Camino del Diablo continues through Organ Pipe Cactus National Monument.

1.2.3 Organ Pipe Cactus National Monument

Designated by presidential proclamation in 1937, OPCNM was established to conserve natural and cultural resources for the public interest. OPCNM encompasses 330,689 acres (133,825 ha) of some of the most biologically diverse areas in the Sonoran Desert. OPCNM covers 26% of the project area, has approximately 169 miles (272 km) of public and/or administrative roads, and shares almost 30 miles (48 km) of the international boundary with Mexico.

OPCNM is considered a living landscape by the Tohono O'odham Nation, which has connections to sacred sites across the monument and conducts seasonal wild-food harvesting traditions there.

1.2.4 Bureau of Land Management–Ajo Block

The BLM manages 62,023 acres (25,099 ha), or 5% of the project area. The public uses the area primarily for recreational use, specifically camping, hunting, and off-highway driving. One active grazing allotment (Coyote Flat #2) occurs within the project area. The BLM issues permits for ephemeral and perennial grazing on that allotment, depending on range conditions. The allotment is currently permitted for 361 AUMs (animal unit months) (BLM 2012).

A recent road survey identified 171 miles (275 km) of public roads in the BLM portion of the project area (BLM 2012). The BLM prepared an environmental impact statement (EIS) for the Lower Sonoran Field Area (BLM 2012), which included a travel management plan to discuss maintenance and status of off-highway vehicular routes. Therefore, the public and administrative road system presented here may change pending finalization of route designations.

1.2.5 Roosevelt Reservation

U.S. federal lands located along a 60-foot (18-m)-wide corridor adjacent to the international boundary with Mexico are required to be kept free of obstructions for the purposes of border security. This designation was established by presidential proclamation in 1907 and is known as the Roosevelt Reservation. Impacts occurring within the Roosevelt Reservation are not assessed here.

1.3 Monitoring of border-related activity in the project area

A marked increase in illegal migration and smuggling activities in southwestern Arizona began in the late 1990s and quickly reached unprecedented levels (DOJ 2002; Milstead and Barns 2002). During this time period, law-enforcement efforts to stem illegal border crossings near urban areas ultimately drove such activities into more remote areas, including the federal lands in this report (DOJ 2002; Milstead and Barns 2002). The elevated rates of border activities in remote locations have generated resource-management issues that are of utmost concern to federal land managers.

In response, federal land managers have worked to quantify the effects of border-related activities on trust resources. Rutman (2005) produced a baseline map of (undesignated) vehicle routes on OPCNM. Remote-sensing methods have been used to monitor or collect data over broad geographic areas. By using remote sensing, areas that are otherwise inaccessible (e.g., due to safety issues, difficult terrain, remoteness), can be inventoried or assessed. A large-scale inventory using such remote-sensing techniques to document (undesignated) vehicle routes was recently completed by CPNWR (FWS 2011).

In this report, we build upon the methodologies developed jointly by CPNWR and OPCNM staff in using remote sensing to detect and classify UVRs across the landscape. In addition, the results of a multi-year research project led by the U.S. Geological Survey, which documents the effects of border-associated activities on soils and vegetation in the project area, are pending publication (USGS–T. Esque, pers. comm., February 21, 2013). Also, the NPS recently produced a State of the Park report that discusses a variety of border issues in OPCNM (NPS 2013).

1.4 Definitions of roads and vehicle routes

Vehicle traffic has occurred on CPNWR, OPCNM, and BLM lands for about 100 years. Horses and wagons were the prevalent form of transportation until the 1930s. There are currently administrative routes and public-use roads authorized by each land-management agency, as well as pre-existing routes and routes that are in varying stages of abandonment and recovery. Table 1-1 shows the different types of designated and undesignated routes in the project area.

Table 1-1. Designated and undesignated route types in the project area.

Road/Route type	Definition
Public Use Road	Roads that agencies have designated as open to public travel. Vehicle traffic is restricted to the established road corridor.
Administrative Route	Routes authorized for limited management purposes only, specific to each agency. These routes may include pre-existing routes that have been identified by the respective land management agency as open for administrative purposes.
Undesignated Vehicle Route (Class 1)	Class 1 UVRs include routes used once or twice. These routes were not the focus of this assessment and are not included on maps in this report. Mileages are reported for these UVRs in Table 3-1.
Undesignated Vehicle Route (Classes 2, 3, and 4)	Class 2, 3, and 4 UVRs include all other multiple-use routes identified in the project area not classified by land managers as either *Public Use Road* or *Administrative Route*. UVRs may include pre-existing routes (see Section 1.5) that were closed by the respective land-management agency.

1.4.1 Pre-existing routes

The escalation of border-related activities throughout the project area began in earnest in the late 1990s; accordingly, 1997 has been established as a base year when UVRs first began to appear on the landscape. Therefore, for the purposes of this report, "pre-existing routes" are those that (1) existed prior to 1997, (2) are visible on the 1997 orthorectified aerial photography, and (3) are not part of each DOI agency's authorized public road and administrative route system. Such pre-existing routes were largely created and used by early ranchers, farmers, and miners who lived and worked in the project area into the 1970s. Pre-existing routes are often long-lived on the desert landscape and were usually clearly visible in recent aerial imagery. Many of these routes were closed in order to restore landscape conservation values after the settlement period ended. We include these routes in the UVR inventory if they have been re-opened (e.g., if fresh vehicle tracks that closely followed the original route alignment were visible), and were visible in the 2008 or 2010 aerial imagery used during this project.

Finally, it is important to note that some administrative routes have been recently created, (e.g., in support of DHS construction activities), while other, previously used administrative routes were abandoned after new administrative routes were created (e.g., old alignments of the road along the U.S./Mexico boundary). Such closed sections of previously used administrative routes are not included in this report.

2 Methods

2.1 Manual digitizing and classification

High-resolution, ortho-rectified aerial imagery and manual photo interpretation were used to document and map UVRs from 2008 to 2010. These years coincide with a period just prior to and after the implementation of the SBI*net* Ajo-1 project. Imagery from 2008, with a ground-sample distance (i.e., resolution) of 30 cm, was obtained through the Department of Defense and covered 100% of the area within 30 miles of the international border and 96% of the project area. The northernmost sections of CPNWR and the BLM–Ajo Block were not photographed in 2008. To map UVRs in 2010, we used imagery publicly available through the National Agriculture Imagery Program (NAIP), with a ground-sample distance of 1 m, which covered 100% of the project area.

Photo grid cells were assigned to each project team member responsible for analyzing imagery. All UVRs visible in the base imagery were manually digitized onscreen and subsequently merged and stored in a common geodatabase in ArcGIS Desktop version 10.0. Optimal photo-display settings within the project area varied depending on ground substrate and photo characteristics, but UVRs were most visible when displayed by stretching raster values along a black and white color ramp, with stretch type set to st dev (standard deviation), and contrast set between 30% and 50%.

Boundary areas between grid-cell groups were reviewed by an expert team member to remove duplicate features and merge UVRs that continued from one grid cell to another. Features were classified into six mutually exclusive categories (Table 2-1; Figures 2-1 to 2-6). To ensure consistency in classifications, the lead team member trained technicians in class definitions with photographic guides and field assessments. Two of the classes (Pre-existing–Used and Wash; see Figures 2-4 and 2-5) are included in the Class 3 category for summary and mapping purposes. Mileages are reported separately for these subclasses in Appendix A.

Table 2-1. Undesignated vehicle route classes and descriptions.

Class	Description
1	Class 1 UVRs were usually used one or two times. The soil between the tracks was undisturbed. Vehicle tracks were clear or faint, and level with the native soil surface or, if the soil was wet when driven on, sunken below the surrounding surface. Some woody perennials were trampled or crushed, but were generally not dead or absent. Some cacti might have been killed.
2	The traffic volume on a Class 2 route was variable. Class 2 routes were sometimes created by 6–20 vehicles on a vulnerable soil or dozens of vehicles on a very stony soil. Vehicle tracks were either level with the native soil surface or sunken below it. The soil between tracks was more or less undisturbed. Woody perennials may have been topkilled or branches crushed, but most were not dead. Cacti were probably killed. The length of the route had pullouts, turnarounds, intersections, or other features indicating that the route had been used multiple times.
3	Twenty vehicles or more had used each Class 3 route, often over a sustained period of time. Vehicle tracks were usually below natural grade, but sometimes level with the native soil surface. The soil between tracks was disturbed. Perennials, including cacti, formerly living in the tire tracks and along the center line of the route were dead. Class 4 UVR sections (see Figure 2-6) were often embedded in Class 3 UVRs.
3 (Wash)	UVRs classed as Wash had traffic contained in wash beds and occurred in drainage systems, such as Kuakatch Wash, on OPCNM.
3 (Pre-existing–Used)	Pre-existing roads occurred prior to 1997 and were distinguished by the alignment of plants along the road edges and sometimes the center line. This type of UVR included pre-existing roads that were re-opened and used after 1997. See Appendix B for an aerial view of an abandoned pre-existing road.
4	Key features of Class 4 polygons were the presence of ≥3 parallel vehicle tracks and damaged or missing vegetation between vehicle tracks. A single line was insufficient to represent the multiple travel paths, so Class 4 lines were coupled with polygons to convey the disturbance area.

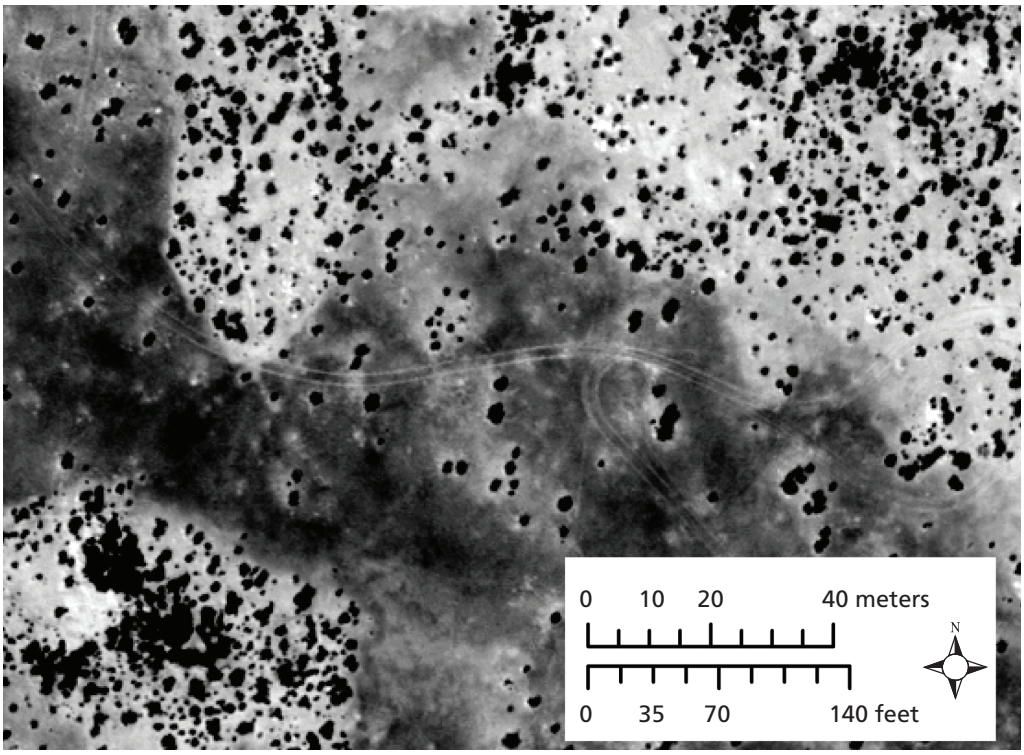


Figure 2-1. Aerial view (above) and ground view (below) of Class 1 UVR.



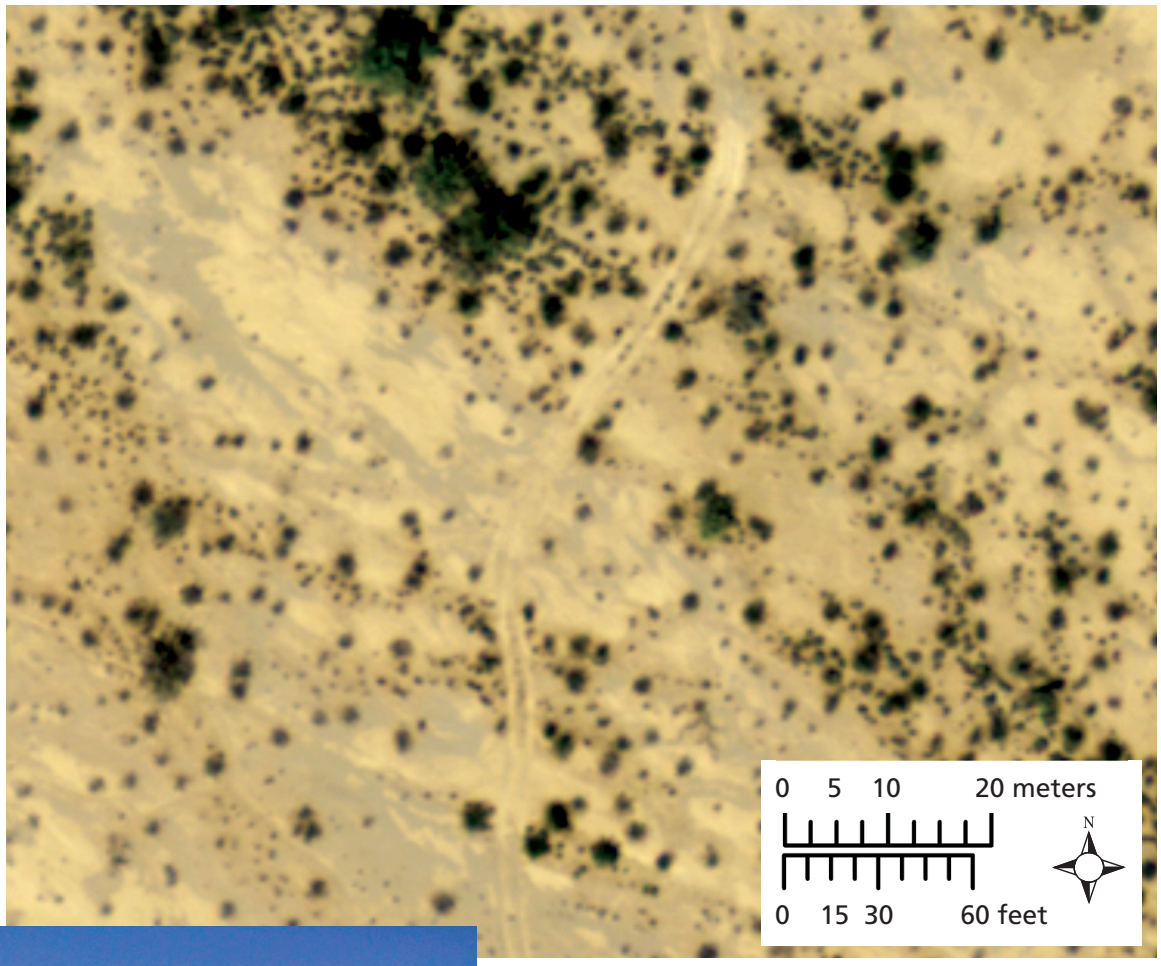




Figure 2-2. Aerial view (above) and ground view (below) of Class 2 UVR. Ground view shows an ATV route near Cholla Pass in the Bates Mountains, Organ Pipe Cactus NM, 2010.

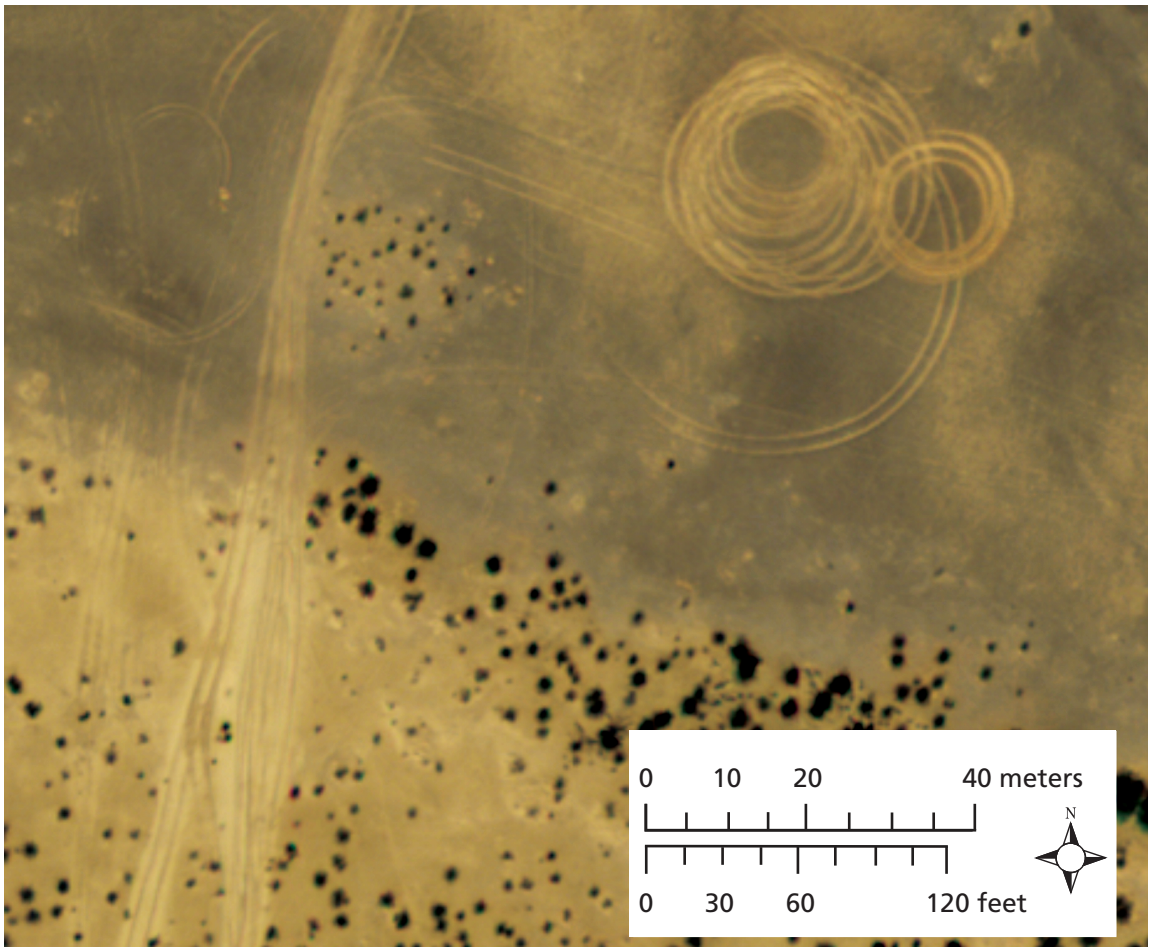


Figure 2-3. Aerial view (above) and ground view (below) of Class 3 UVR. Aerial view shows a Class 3 section of the Los Vidrios route on Cabeza Prieta NWR. Ground view shows a Class 3 UVR in the San Cristobal Valley, Organ Pipe Cactus NM, 2010.



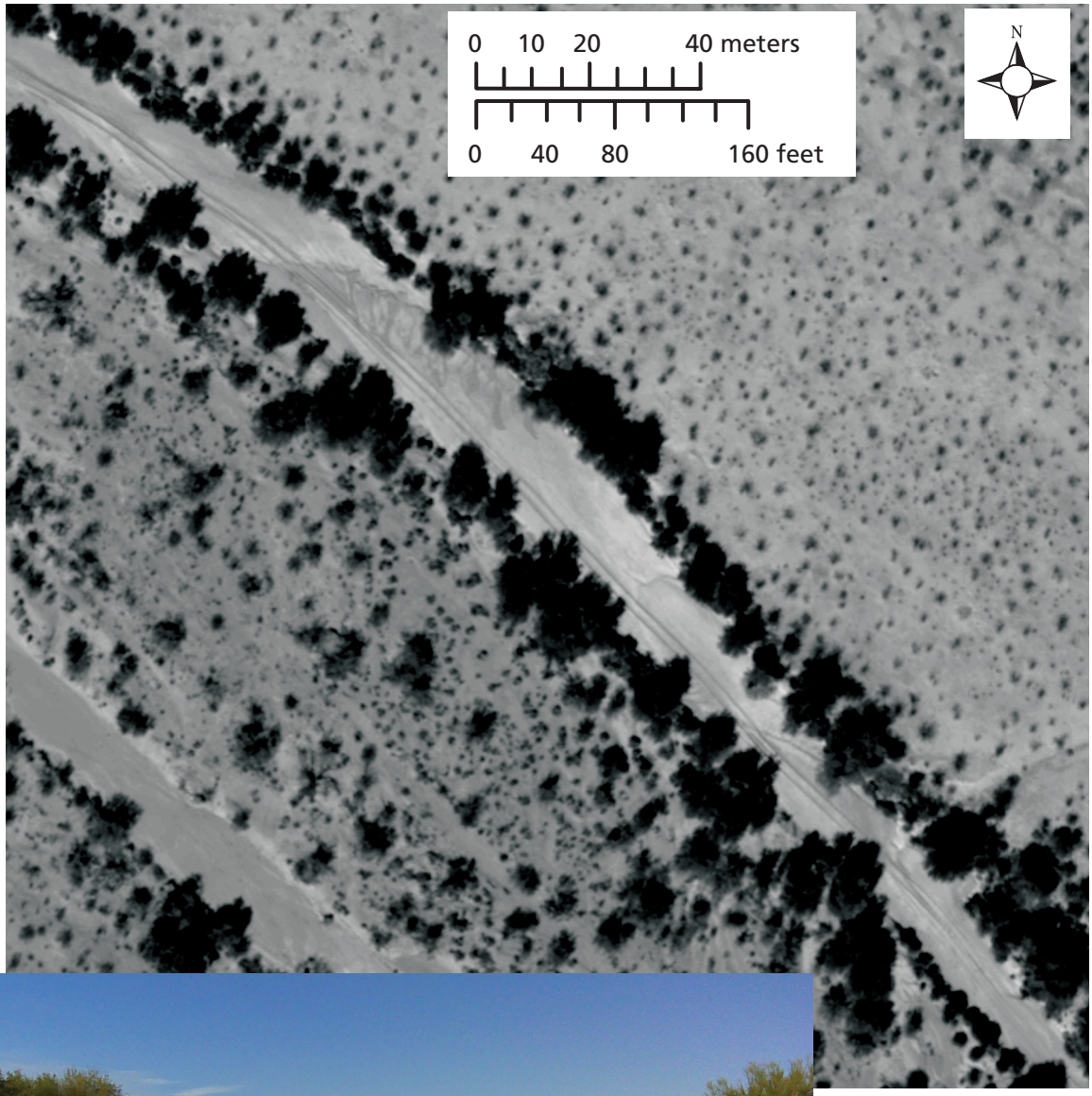




Figure 2-4. Aerial view (above) and ground view (below) of UVR Class 3–Wash. January 2011.

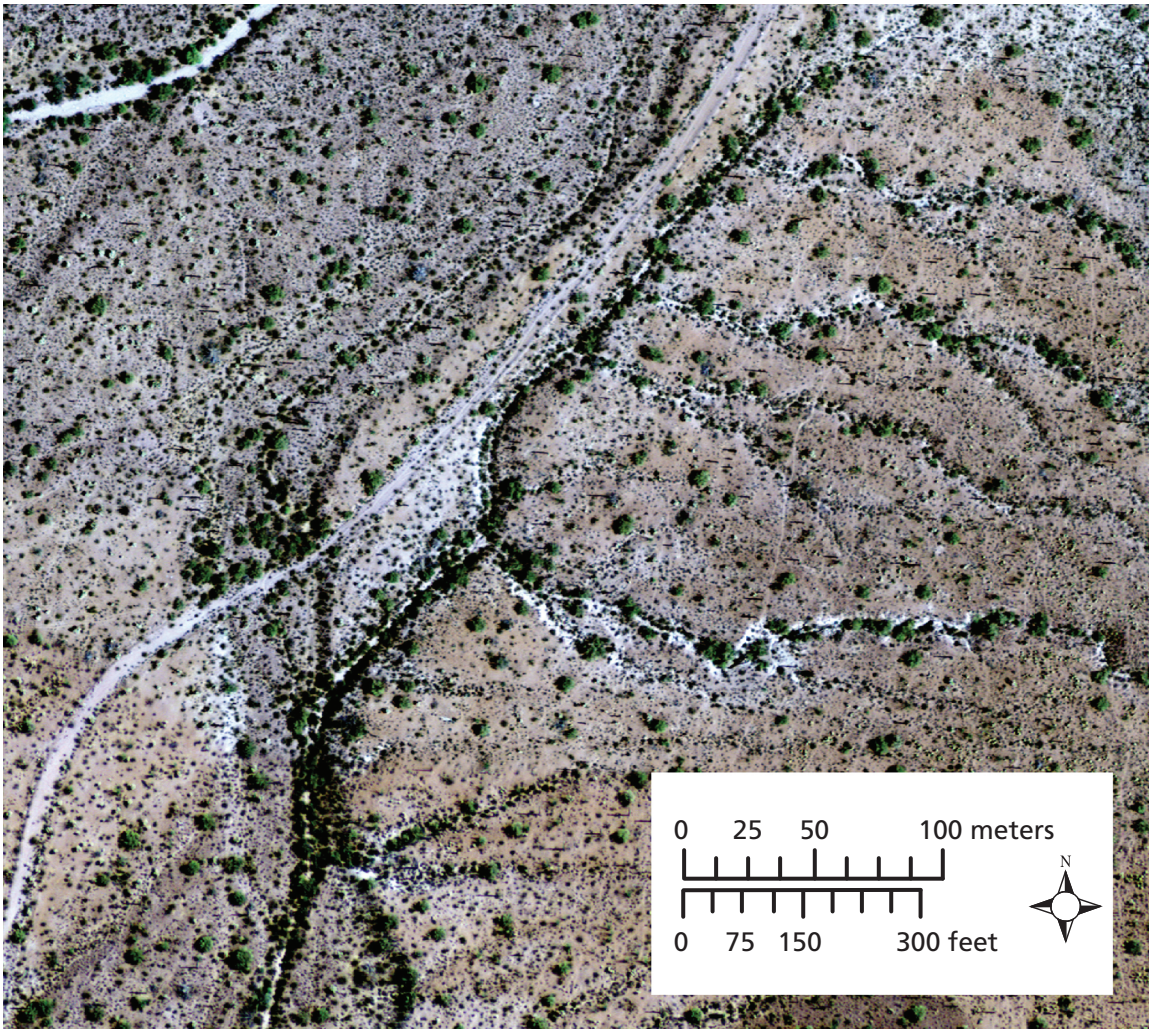


Figure 2-5. Aerial view (above) and ground view (below) of UVR Class 3–Pre-existing–Used, circa 1970. Note undesignated foot trails are also visible in top photo above scale bar, to right of UVR.



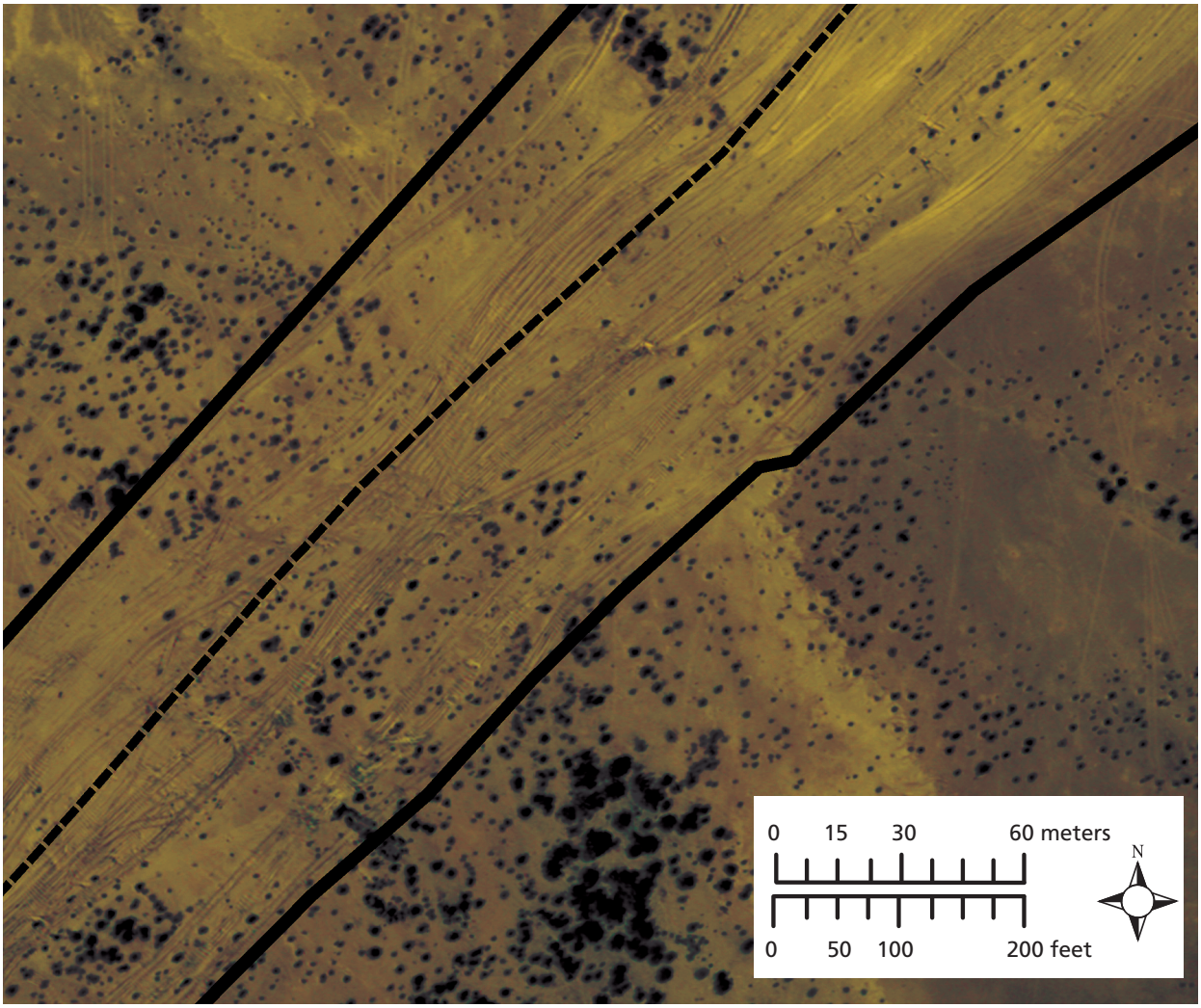




Figure 2-6. Class 4 UVR in the Growler Valley, Cabeza Prieta National Wildlife Refuge, from aerial photograph (above) and photo taken during a low-elevation flight (below). Ground photography does not adequately capture the scale of Class 4 lines and areas. Heavy black line (above) indicates Class 4 polygon boundary and dashed line is the location of the most heavily traveled route on 2008 imagery.

Feature classification at CPNWR differed slightly from that at OPCNM and the BLM–Ajo Block, and thus required more post-editing by staff. Digitizing for 2008 at CPNWR was conducted over a six-month period by a team of four staff members. This team used a draft classification system that differed from the final classification system outlined in Figures 2-1 to 2-6. Therefore, this dataset was treated as preliminary data and subjected to a series of standardized tests (see below) before integration with the remaining data. Digitizing for 2008 at OPCNM/BLM was conducted over a six-month period by a team of two staff. Digitizing for 2010 was conducted for the entire project area over an additional six-month period by a team of two employees. In addition, public and administrative road inventories were completed or updated on CPNWR and BLM, a necessary prerequisite for determining the status and origin of newly mapped vehicle routes.

Several assessments were conducted during digitizing to assess inter-observer agreement in trail detection and classification using kappa statistics (Cohen's kappa, Cohen 1960; and Fleiss's kappa, Fleiss et al. 2003) and a random subset of features and screenshots. A set of 50 random points was created using ArcGIS and used in several subsequent tests. In the first test, a test administrator extracted a set of CPNWR's draft digitized features near the random points and submitted the set to remaining OPCNM team members.

Team members were asked to identify the feature as either a vehicle or non-vehicle feature, and then asked to assign a class if identified as a vehicle feature. In the second test, the set of random points was buffered by 50 m and team members were asked if all vehicle features had been mapped satisfactorily within the buffer boundaries. If answered in the negative, observers recorded how many line parts they would add or subtract from the digitized layer. Lastly, a random subset of 30 of CPNWR's draft digitized features placed in the highest-impact classes (i.e., tracks used by multiple vehicles, used over prolonged time periods, or both) was extracted and tested using the methods described above to assess inter-observer agreement on more well-used UVRs.

The output of these tests was then used to train and standardize team-member classifications during the final editing phase (Appendix C). In addition, this testing was used as a preliminary assessment (prior to ground-truthing, see next section) of how often team members agreed on features falsely identified as vehicle tracks and vehicle features missed during digitizing.

After assessment of the draft CPNWR data, all data were merged and a final review of all features was completed by an expert team member. In this final version, UVRs were geometrically smoothed (i.e., line segments were joined across gaps in visible vehicle-track features if less than 200 m in length).

It was recognized early in the mapping process that UVRs were not detectable in mountainous terrain or in areas with high slope values, mostly due to the presence of bedrock or the coarseness (rockiness) of the substrate. Including these areas in estimates of UVR densities per unit area would underestimate actual UVR density. Therefore, we excluded high-slope areas from density calculations by the following process. A raster dataset for slope was created for the project area using a 10-m digital elevation model (DEM). The UVR vector data were converted to raster format and then overlaid with the slope raster. This enabled us to calculate the highest slope value where UVRs occurred. Areas with slope values higher than this maximum value were then excluded in subsequent UVR density per unit area calculations.

2.2 Ground-truthing

Although field verification of digitized features was not specifically coordinated to coincide with the acquisition date in 2008, several field efforts compatible with ground-truthing were conducted close in time to the photo acquisition date. These data were used to verify presence or absence of features. This group of ground features was assumed to be representative of UVR classes.

Photography from 2008 was acquired during October–November. Field work occurred 0–7 months after the photo date (CPNWR, November–February 2009; OPCNM, May 2009). Further field work occurred after the 2010 photo data were acquired in January–February 2011. Class 1 features were only

mapped on the 2008 base imagery, so we used the 2008 dataset to estimate traditional commission and omission error rates for all features. Ground-truthing was conducted in several phases that are detailed in the following sections.

2.2.1 East–west transects

Biennial surveys conducted on both CPNWR and OPCNM document border impacts along nonrandomized transects. Along these transects, foot trails and vehicle tracks are recorded using handheld GPS units (Holm and Pate 2006). A subset of vehicle tracks found in these surveys was used to ground-truth digitized features.

We recorded as false negatives features detected in the field but not identified on the digitized layer. Features recorded in the field were buffered by 20 m to allow for positioning error in GPS, visually inspected to find a match to a digitized feature within this buffer zone, and counted as false negatives if no match existed. (Due to the time gap between photo acquisition dates and field verification, we were unable to determine if such features were missed during digitizing or created after the photo acquisition date.)

We recorded as false positives features that were identified on the digitized layer but not detected in the field within a buffer zone of 20 m on either side of the pre-determined transect line (i.e., features falsely identified as vehicle tracks during digitizing).

Key assumptions for ground-truthing included: (1) ground observers walked reasonably straight lines when conducting transects, (2) ground observers detected 100% of vehicle features within 20 m of the transect line, (3) inter- and intra- ground observer detection rates were relatively consistent, (4) GPS positions were accurate within 20 m of digitized segments, and (5) ground observers did not generalize separate vehicle tracks into single GPS waypoints unless there was an intersection of up to three routes.

2.2.2 Percent matching

Using the final digitized layer of Class >1 UVRs, we assessed how often digitized features matched a vehicle feature recorded in the same location in the east–west transect data. We were unable to assess false negative and false positive rates on Class >1 features due to a lack of similarity in feature attributes between the field and digitizing protocols (i.e., vehicle features mapped in the field were attributed with data describing amount of use, age, etc., that differed from that of our UVR classification system). The percent of matching features was calculated as the total number of matches divided by the total number of digitized features.

2.2.3 Road surveys

A field survey was completed in 2011 to document UVRs on OPCNM where they intersected with public and administrative roads. The road survey protocol treated public and administrative roads as sampling transects to document presence and persistence of UVR features. Features contained within 100 ft (30 m) of the road corridor (e.g., turn-arounds, pullouts) were not recorded by the field crew and were not included in the ground-truthing comparison if they were present in the digitized layer. Field work was completed by 2–3 observers, driving at speeds <10 mph (16 kmh) while searching for UVR intersections. UVR positions were recorded with a GPS and features were classified using the same class system used for digitizing. Key assumptions were: (1) ground observers detected 100% of vehicle features within 30 m of the road transect, (2) inter- and intra- ground-observer detection rates were relatively consistent, and (3) GPS positions were accurate within 20 m of digitized segments.

Features mapped in the field were compared with the digitized Class >1 UVR layer, and the numbers of false negative and false positive errors were tallied. We excluded features classified as Class 1, unless either digitizers or ground crew had mapped a higher-class feature in the same position, due to the large time gap between digitizing and field work (three years). Digitized and ground-mapped features that occurred in the same position but were classified differently between the two groups were evaluated as traditional false negatives and false positives. Class agreement was calculated as the total number of features for which both groups agreed on class, divided by the total number of features evaluated.

2.3 Ground-mapping and post-2010 updates to UVR map

Some UVRs were created after the 2010 imagery was captured. Because NPS staff was familiar with many of the tracks and vehicle routes described in this report for OPCNM, we also used expert knowledge and conducted interviews with NPS law-enforcement rangers to locate UVRs. These were mapped on foot using handheld GPS units and subsequently added to the final layer of UVRs. Imagery from 2011 available in Google Earth version 6.2 (ground sample distance 1 m) was also searched to find previously undocumented UVRs; these were added to the final dataset. A similar effort did not occur on CPNWR or BLM.

3 Results

3.1 Linear miles of UVRs

During the digitizing process, 9,326.9 miles (15,010 km) of UVRs were documented (Table 3-1). Forty additional UVR miles created after summer 2010 were also opportunistically recorded, resulting in a total of 9,366.9 UVR miles documented in the project area.

Ninety-two percent of UVR mileage was categorized as Class 1 (usually single-use vehicle tracks), 3.1% was classified as Class 2, 4.7% was classified as Class 3, and 0.2% was classified as Class 4. There were 742.5 miles (1,195 km) of Class >1 UVRs documented; Table 3-1 shows the total length of each UVR class by land-management unit. For classes 1, 2, 3, and 4 respectively, the average UVR widths were estimated to be 7.2 feet (2.2 m, range 4.9–8.9 ft/1.5–2.7 m), 7.9 feet (2.4 m, range 6.2–10.1 ft/1.9–3.1 m), 8.4 feet (2.6 m, range 5.9–11.1 ft/1.8–3.4 m) and 148.3 feet (45.2 m, range 26.2–482.2 ft/8–147 m).

3.2 Class 4 disturbed areas

The total area mapped in Class 4 polygons was 0.7 mi^2 (1.9 km^2). This area comprised 41 unique polygons, most (75%) of which occurred on or within 200 m of an administrative road. Class 4 areas generally evolved over time as traffic moved around obstacles, such as deeply entrenched road sections, deep ruts, dust pits, or wet areas. Most Class 4 areas occurred on CPNWR; three occurred on OPCNM, three on BLM, and four occurred along the boundary between CPNWR and OPCNM. The largest of these areas was only 0.3 mi^2 (0.75 km^2) in area, but stretched for >3 mi (5 km) along one of CPNWR's administrative roads and was >490 ft (150 m) wide for more than half its length. The smallest area was 0.0003 mi^2 (0.001 km^2) in area and slightly less than 200 ft (60 m) in length.

3.3 UVR density

Shaded areas depicted on Figure 3-1 represent areas of high UVR density; darker shades indicate areas with at least 0.5 mi of UVR per mi^2 (0.8 km/2.6 km^2) of land area. The Growler Valley, in southeastern OPCNM (Figure 3-2), and a section of the BLM–Ajo Block near State Route 85 (Figure 3-3), where long-term recreational camping occurs, had the highest UVR densities (>2.0 mi UVR per mi^2/>3.2 km per 2.6 km^2). Figure 3-1 also highlights other areas of concentrated UVR use.

UVRs were not detected in areas with slope values of >37.4%. There were 16,444 ac (6,655 ha) in the project area (approximately 1% of total project area) above this slope value.

3.4 Expansion in the UVR network, 2008–2010

In 2010, there were 65 new Class >1 UVR miles that were not present in 2008 (Figures 3-4 to 3-7; Class 1 features were not mapped in 2010—see Methods). Most new detections were Class 3 features, although 15.9 of the new UVR miles were Class 2 and one additional Class 3-Wash UVR was detected. No new Class 4 features developed in the two-year time period. Between 2008 and 2010, fourteen pre-existing roads or road sections (24.6 mi/39.6 km) changed status from abandoned to UVR Class 3. Most new UVR development was concentrated in the southeastern corner of OPCNM and along an administrative road corridor in western OPCNM (Figures 3-8, 3-9). An expansion of the UVR footprint within the project area has continued since 2010, as exemplified by the documentation of 40 additional miles of UVRs within portions of OPCNM using imagery from 2011.

Table 3-1. Number of miles documented during digitizing by land agency in the project area, 2008–2010.

Management unit	Land area (acres)	Class 1	Class 2	Class 3	Class 4	Subtotal, Classes 2–4	Grand total
CPNWR	860,010	7,488.5	197.0	174.0	16.7	387.7	7,876.2
OPCNM	330,689	954.1	56.5	198.4	0.8	255.7	1,209.8
BLM–Ajo Block	62,023	141.8	32.4	65.6	1.1	99.1	240.9
Total	**1,252,722**	**8,584.4**	**285.9**	**438.0**	**18.6**	**742.5**	**9,326.9**

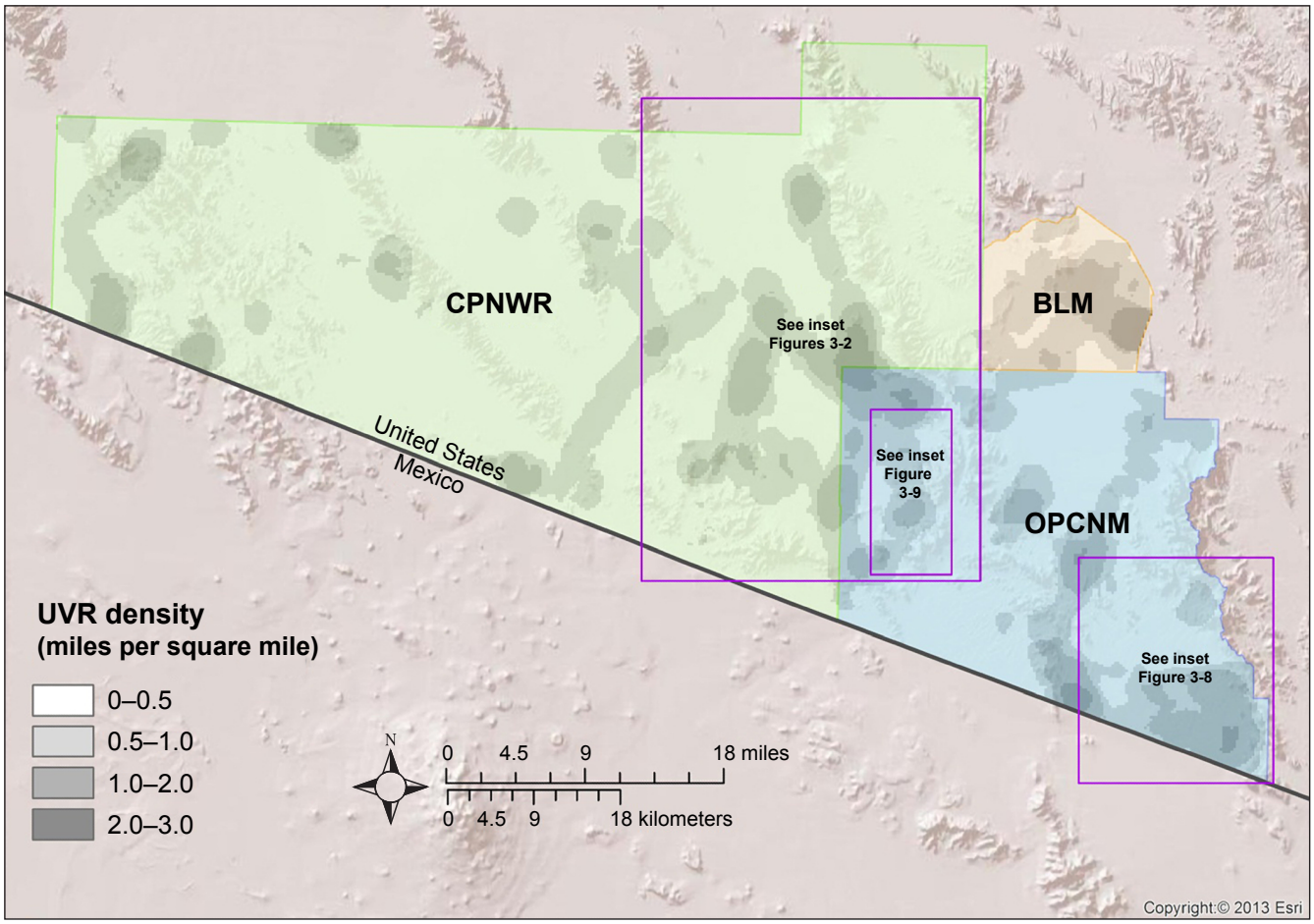


Figure 3-1. UVR density across the project area.

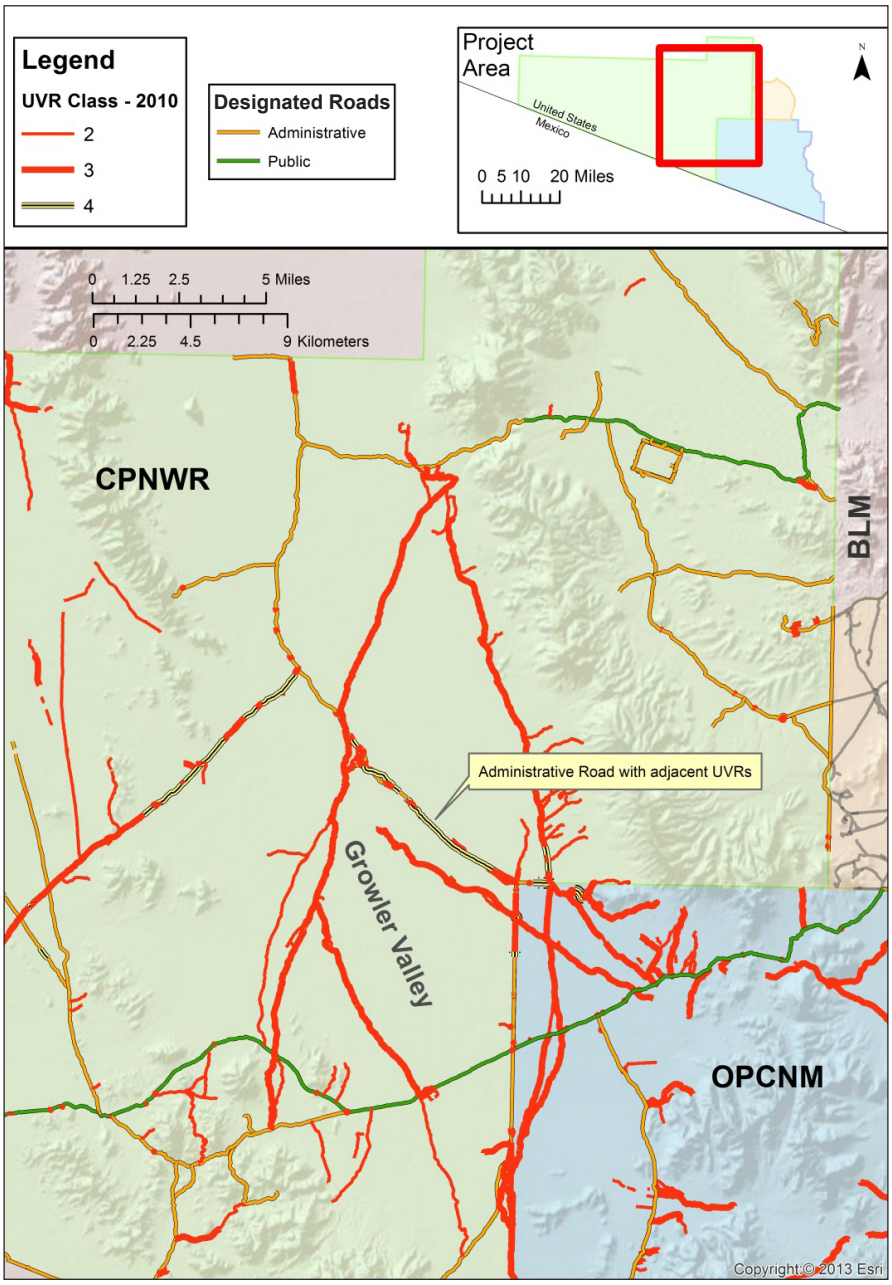


Figure 3-2. UVRs in Growler Valley, Cabeza Prieta NWR and Organ Pipe Cactus NM.

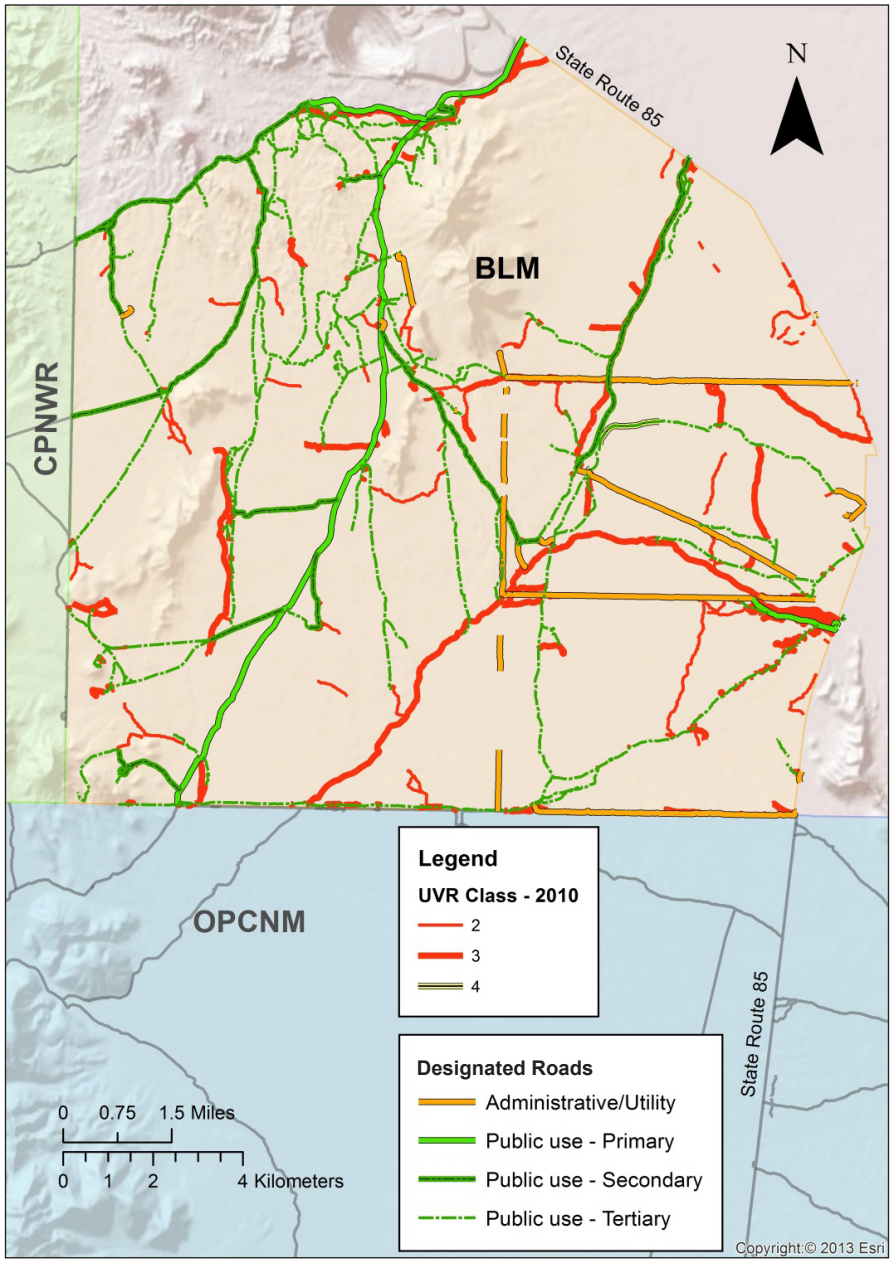


Figure 3-3. UVRs on BLM–Ajo Block, 2010. (The northernmost sections of Cabeza Prieta NWR and the BLM–Ajo Block were not photographed in 2008.)

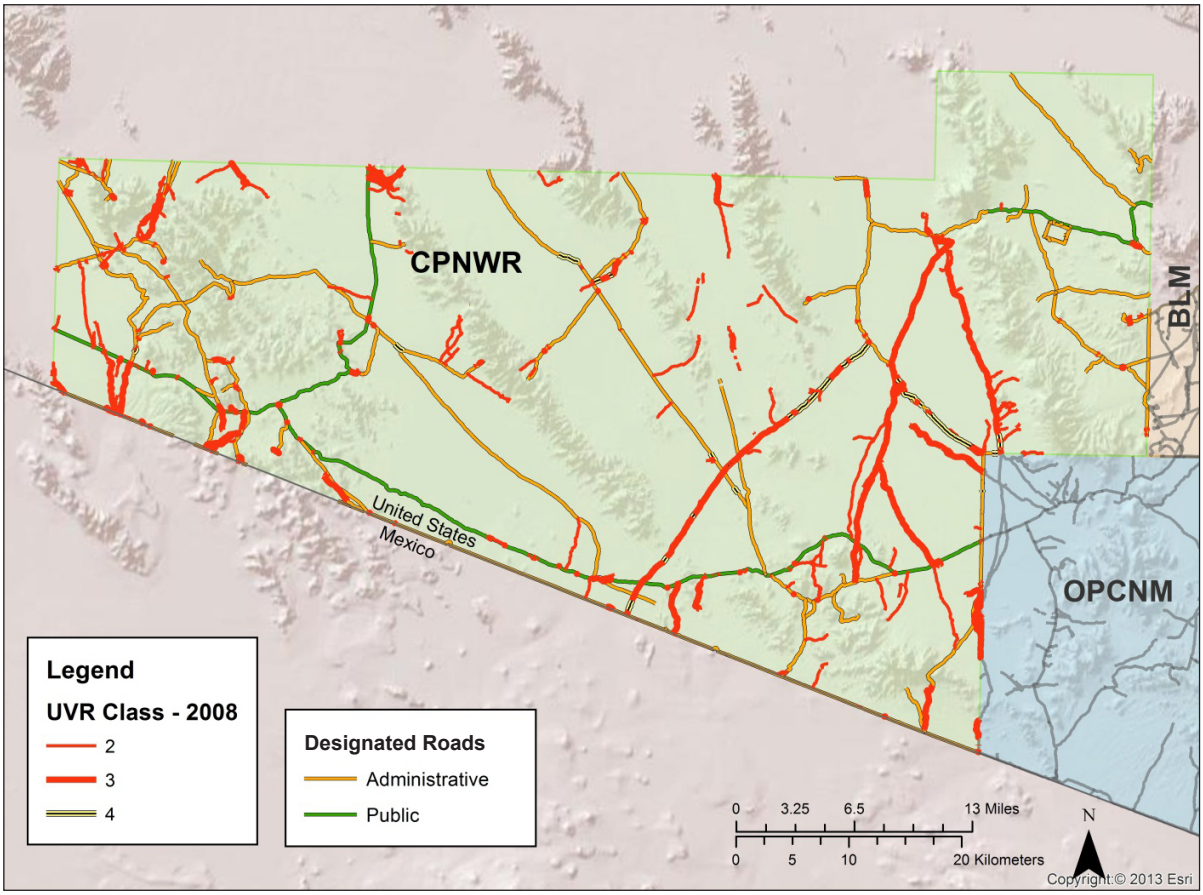
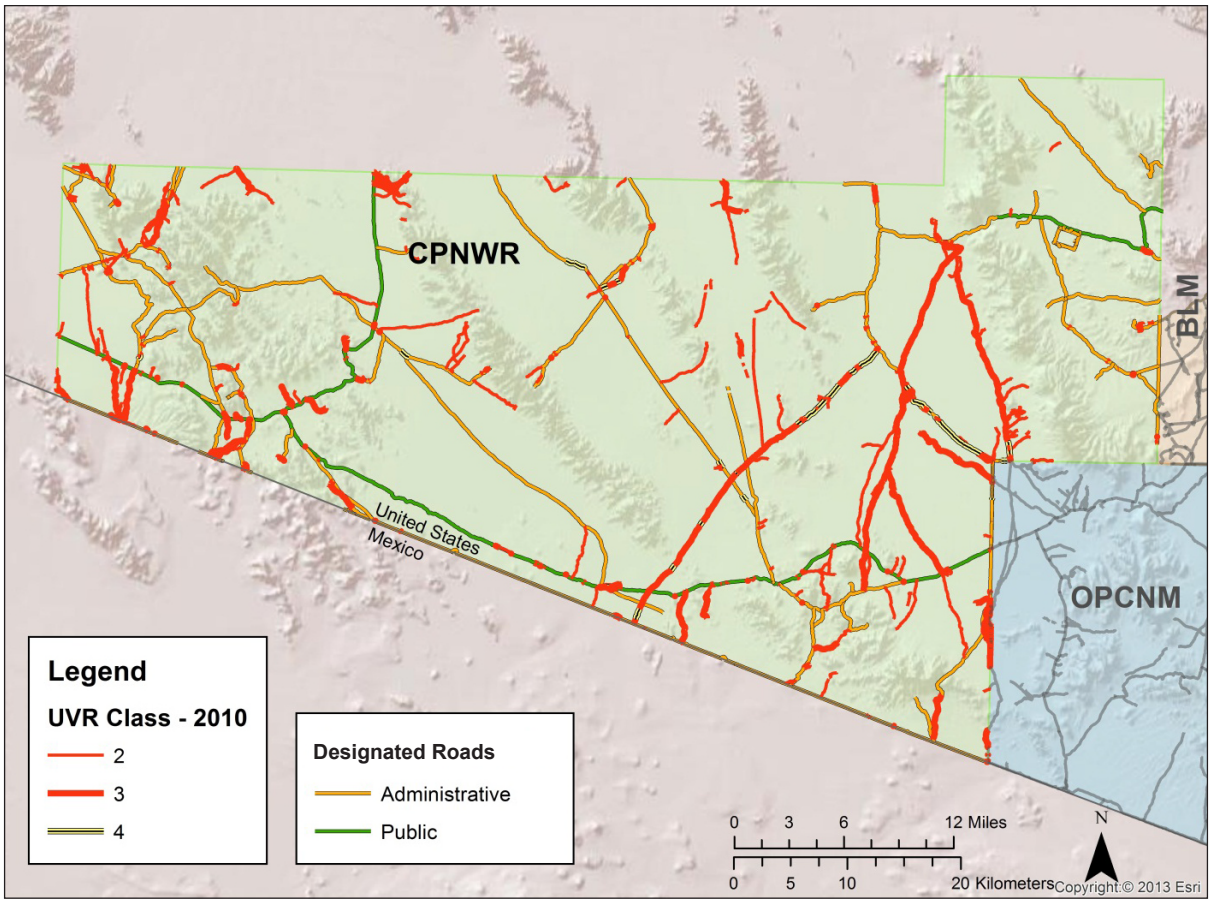


Figure 3-4 (above). UVRs on Cabeza Prieta NWR, 2008.
Figure 3-5 (below). UVRs on Cabeza Prieta NWR, 2010.



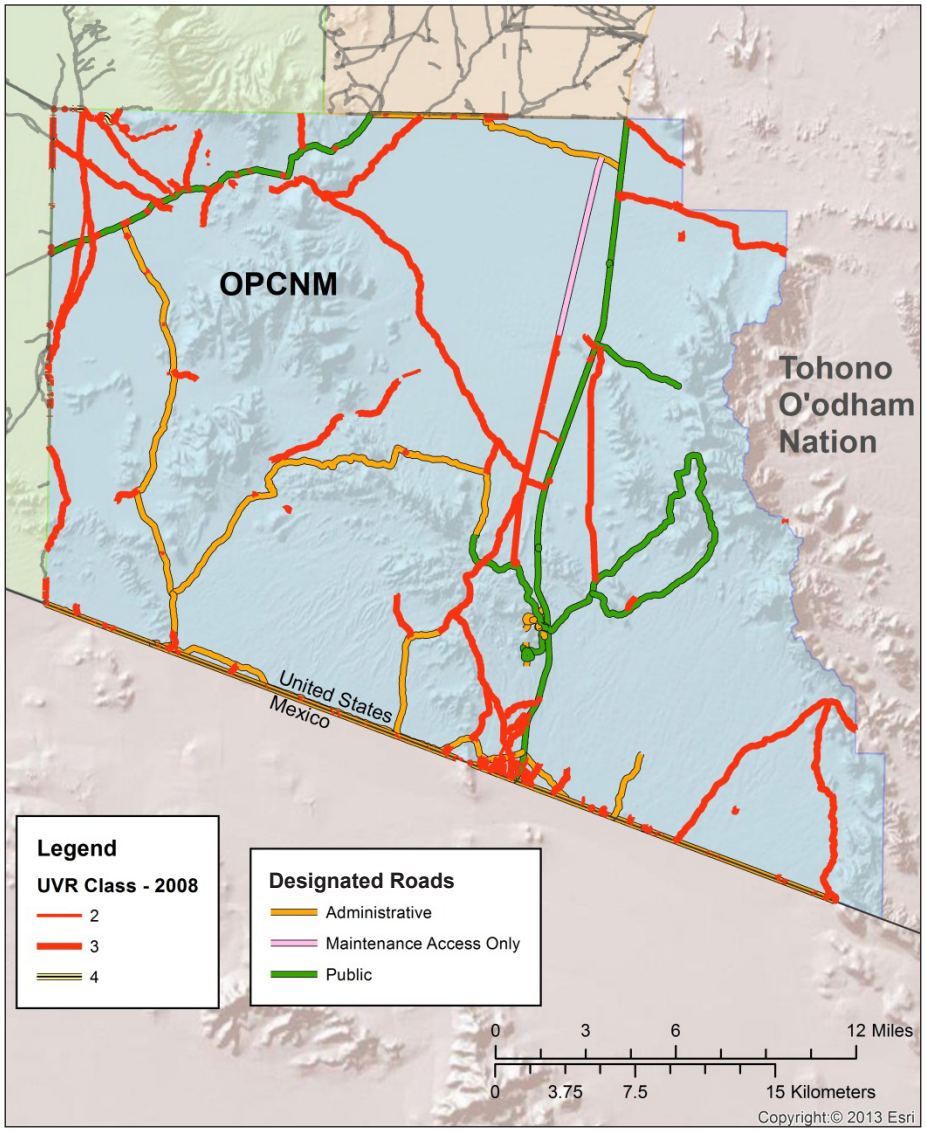


Figure 3-6. UVRs on Organ Pipe Cactus NM, 2008.

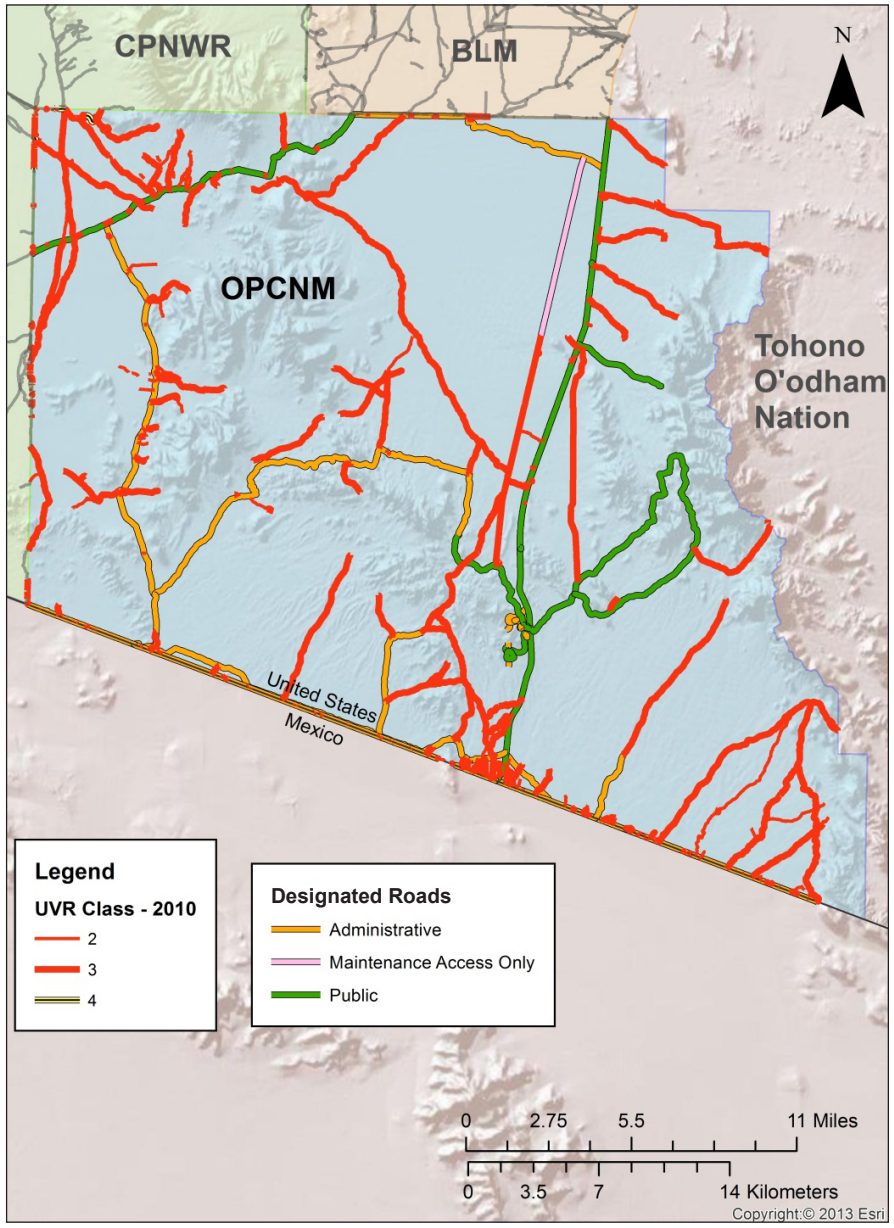


Figure 3-7. UVRs on Organ Pipe Cactus NM, 2010.

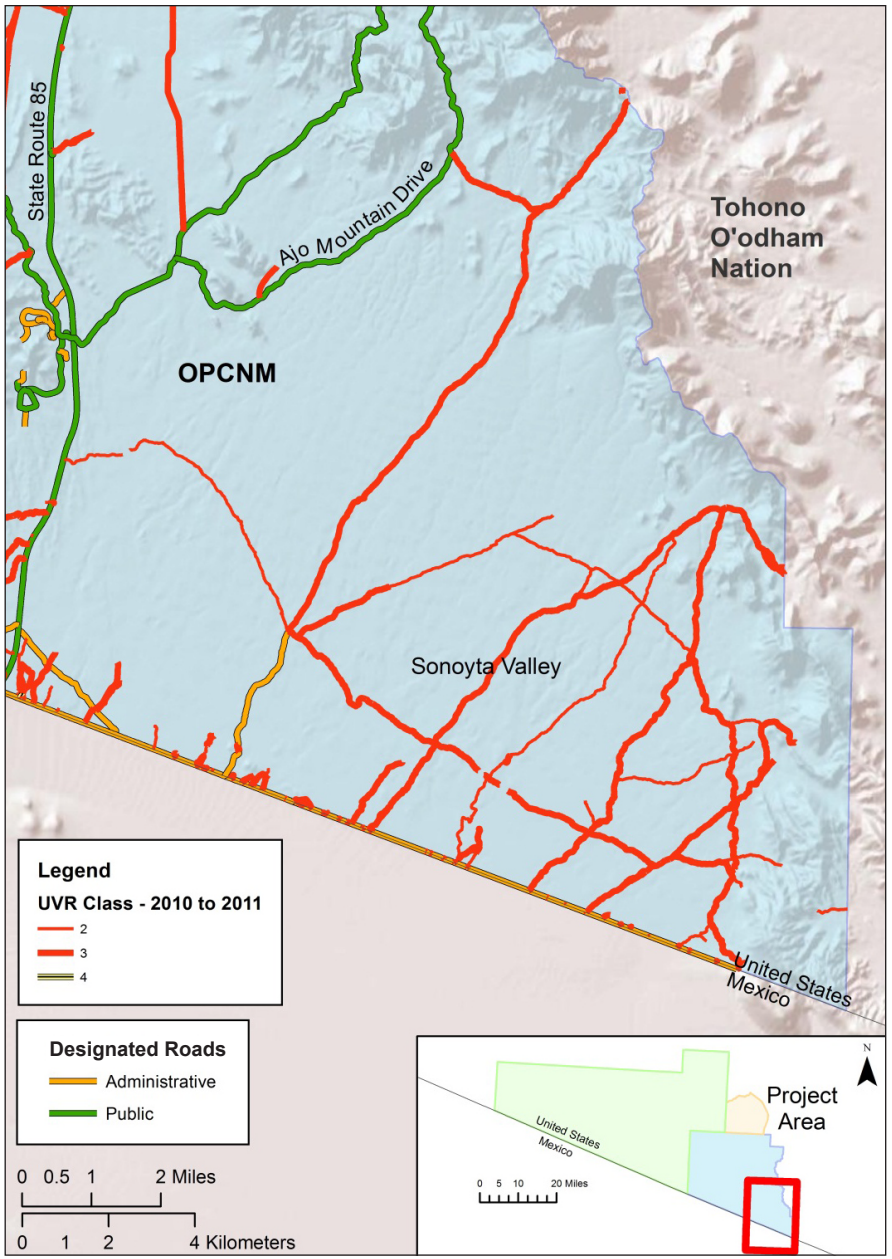


Figure 3-8. UVRs in southeastern Organ Pipe Cactus NM.

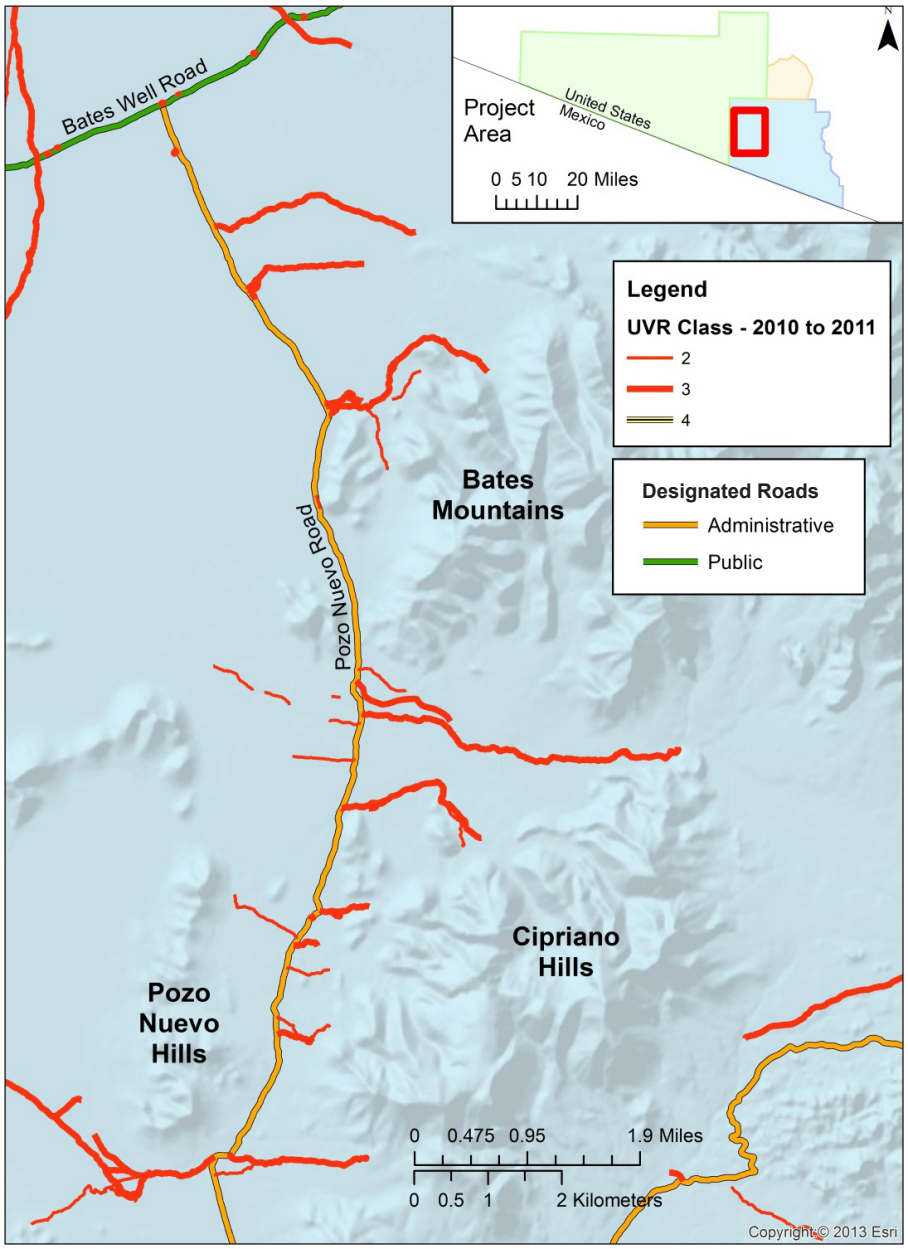


Figure 3-9. UVRs along the administrative Pozo Nuevo Road in western Organ Pipe Cactus NM.

3.5 Detectability of UVR classes

There were differences in detectability of UVR classes between the 2008 and 2010 imagery. Most notably, Class 1 UVRs were visible in 2008 imagery, but only rarely visible in the lower-resolution 2010 imagery. Class 2 UVRs were visible in the 2008 imagery, but only some of these were also visible in the 2010 imagery (we assumed Class 2 UVRs did not undergo visual recovery in the two-year timespan between photo dates). Class 3 UVRs and Class 4 disturbed areas were clearly visible in both imagery sets.

3.6 Ground-truthing

3.6.1 East–west transects

False positive rates on 16 east–west transects ranged from 0.0 to 76.7%. False negative rates ranged from 8.7 to 76.7%. The average false positive and false negative rates over all transects was 22.2% (± 18.2) and 43.5% (± 19.7), respectively (Appendix D). The average number of comparisons between the east–west layer and digitized features was 63.0 (± 55.5; range 7–222).

3.6.2 Percent matching

Matching of Class >1 UVRs with east–west transect data yielded average percent match estimates of 90.6 ± 17.8 (range 50.0–100.0; Appendix D). Ten of fifteen transects had at least two intersections, the minimum number required to enable comparisons between the digitized layer and field data. The average number of comparisons (3.4 ± 2.9, range 2–10) between the east–west layer and the digitized features was much lower than the east–west transects, due to the exclusion of Class 1 UVRs (see Methods). This was due in part to the relative rarity of Class >1 on the landscape as compared to Class 1 UVRs.

3.6.3 Road surveys

The average false positive rate on all road surveys was 2.6% (±0.5). The average false negative rate was 15.2% (±13.8) (Appendix D). The average number of comparisons between the road survey layer and digitized features was 20.3 (±17.1; range 4–54).

4 Discussion

Using aerial imagery from 2008 and 2010, more than 740 miles of repeatedly used undesignated vehicle routes were documented across three land-management units during this project: Cabeza Prieta National Wildlife Refuge, Organ Pipe Cactus National Monument, and the Bureau of Land Management–Ajo Block. Some UVRs were concentrated spatially around landscape features, such as administrative roads and unit boundaries. A variety of other factors, including topography and landscape features, also influenced the location and distribution of UVRs across the project area. Growler Valley, the most significant pronghorn habitat among high-density UVR areas, was a focal point for vehicle traffic through 2010.

The remote-sensing techniques used in this UVR inventory likely underestimated UVR mileage in the project area, due to variable UVR detection rates. Therefore, the results documented here provide an informative yet incomplete picture as to the actual expanse of the UVR network present when the imagery was captured in 2008 and 2010. Ongoing increases in UVR occurrences continue to fragment and degrade high-quality Sonoran pronghorn habitat, as evidenced by the documented expansion of UVRs between 2008 and 2010, and continued expansion after 2010. Of particular concern is the continued expansion of Class >1 UVRs documented in this report, which is inconsistent with the anticipated outcome outlined in the U.S. Fish and Wildlife Service's biological opinion for the U.S. Border Patrol's Secure Border Initiative Ajo-1 Tower Project (FWS 2009). In accordance with that BO, this report is intended to assist with the identification of UVR restoration opportunities to be conducted over the next several years.

4.1 Topographic influence on vehicular travel

Topographic features in the project area influenced vehicular travel in several ways. In the southeastern portion of OPCNM, vehicle routes were primarily restricted to the high terraces of dissected bajadas, where low plant cover and flat, hard surfaces lend themselves to easier vehicle access. In contrast, broad, flat stretches in the Growler Valley, with little topographic relief, have very few obstacles to restrict vehicle routes. Beyond these generalizations, there are other features of the landscape that add to the complexity of spatial patterns in UVRs. For example, despite being surrounded by relatively flat terrain, vehicle travel on the Christmas Pass Road, on CPNWR, is restricted in some places to the main road alignment, where the road itself is too far below the surrounding ground surface to allow vehicles to exit (S. Rutman, pers. comm., July 5, 2012).

4.2 UVR inventory techniques

The results of this UVR inventory are conservative, given the variable UVR detection rates on different substrates and soil types. We propose three primary explanations for this variability in UVR detection rates: (1) Vehicle tracks were difficult to detect on surfaces that lack the soil horizon development that can cause color changes between soil surfaces and sub-surfaces. This color contrast often aided us in detecting vehicle tracks, especially on surfaces such as desert pavements, where vehicle tires disturb the dark brown-to-black rocky surface and expose the underlying, lighter-colored, silty, clay layer (or vesicular A horizon, a distinct, fine-grained soil horizon located just under the layer of stones that form a desert pavement surface). A lack of color contrast may also explain why vehicle tracks were less detectable on certain other soils, where there is little color contrast between the surface and sub-surface (such as deep valley bottom soils). (2) Unstabilized sand dunes in the project area were problematic because vehicle tracks were removed by wind erosion, quite rapidly becoming less visually detectable. (3) We could not reliably detect vehicle tracks on caliche surfaces or in mountainous areas, mostly due to the coarse substrate (large cobbles, boulders, or bedrock), where vehicles would not reasonably create a significant track unless an engineered road was present. Some of this terrain is also too steep to be navigable by motorized vehicle. However, these high-slope areas constituted a minor portion of the project area (< 1%).

UVR age also appeared to influence visual detectability. Newly created vehicle tracks (less than approximately five years old) often appeared brighter in the imagery compared to the surrounding substrate. On older UVRs that had previously experienced high traffic rates but were closed or infrequently used by 2008, this brightness was diminished, possibly due to the return of annual plant cover. The greater age of these UVRs was nevertheless apparent due to the development of erosional features, such as rills, along the road alignment. The presence of erosional features

was an important indicator of road age for both UVRs and for detection of pre-existing roads. Roads more than 50 years old generally had diagnostic linear alignments of plants along the road shoulders and sometimes down the center line.

Overall, UVRs were much more frequently missed (as opposed to falsely identified) during digitizing due to variable detection rates. Therefore, a more complete inventory may yield a higher, rather than lower, estimate of UVR mileage. There was generally good agreement in detection of well-used UVRs between the digitizers and ground-mapping crews. This suggests that much of the error may be attributable to the presence of Class 1 features in the dataset, which were not the focus of this inventory.

In response, we developed a classification system that enabled us to document the location of the most frequently used UVRs. To arrive at this subset of features, we chose to map 100% of visible vehicle features and then later removed single-use or infrequently used (Class 1) UVRs. We recognize that this high level of effort may not be possible in other large geographic or high-use areas. A classification system, such as the one used here, should be used in future studies to simplify the mapping process. In addition, it may be appropriate to consider using automated detection methods, although they require considerable software expertise and some level of manual interpretation (reviewed in Quackenbush 2004) and have previously met with limited success in the project area (L. Nelson, pers. comm., August 8, 2012). Assuming digitizers have good agreement rates on UVR detection and classification prior to the start of mapping, it may be feasible to choose UVR types of specific concern on which to focus mapping efforts. In smaller geographic areas or low-use UVR areas, a complete inventory could be performed with much less effort than this inventory required. Nevertheless, inventories for any type of area will likely require a significant time investment, both in the digitizing process and in ground-truthing, as well as in data management.

We encourage the further development of remote-sensing techniques as a feasible strategy for mapping UVRs, with the caveat that any product should be supported by ground-truthing efforts to assist in estimation of error rates. In addition, we suggest stratifying ground-truthing by soil types, or at a minimum, basins or sub-basins with a similar geomorphic setting.

4.3 Expansion of UVRs and potential impacts on Sonoran pronghorn

An expansion of the overall UVR network was documented from 2008 to 2010. This expansion continued into 2011. In OPCNM alone, at least 40 new miles of Class >1 UVRs were created between 2010 and August 2011, as recorded by opportunistic surveying. These newly identified UVRs were scattered throughout OPCNM; similar exercises were not conducted on CPNWR or the BLM's Ajo Block. High UVR concentrations were often located along lengths of administrative or public roads or along other landmarks, such as the southern section of the CPNWR–OPCNM land-management boundary.

This continued expansion of UVRs is of utmost concern to land managers responsible for Sonoran pronghorn recovery, because UVRs fragment and degrade Sonoran pronghorn habitat and increase the opportunity for more frequent human–pronghorn interactions. Limiting such interactions has been, and continues to be, a priority for Sonoran pronghorn management and recovery—particularly during the fawning season, as well as during the prolonged hot and dry periods that frequently occur in the extreme Sonoran Desert environment.

The Growler Valley, for example, which is shared between CPNWR and OPCNM, had the highest UVR density in the project area. The largest Class 4 disturbed areas occurred there, as well, suggesting that the valley is a focal point for vehicle traffic. This is of particular concern not just because of the direct ecological influence of such abundant impacts (e.g., soil compaction, linear entrenchment, and consequent alteration of life-sustaining hydrological processes), but also because the Growler Valley constitutes prime Sonoran pronghorn habitat, in part due to its large size, (formerly) pristine habitat condition, and remoteness.

Although the primary goal of this inventory was to document and assess UVRs in order to inform ongoing Sonoran pronghorn management and recovery efforts, understanding the ecosystem-level influence of the presence of >9,000 miles of vehicle tracks clearly warrants consideration at both the localized and landscape scales. The vast majority of mileage recorded during this inventory fell into the Class 1 category. Although the Class 1 designation implied a relatively lighter impact on the landscape, the ecological impacts

of off-road travel should be considered both at the scale of single features and landscape-scale effects (Brooks and Lair 2009).

4.4 Restoration potential and needs of UVR-impacted areas

Several factors influence the restoration potential and needs of UVR-impacted areas. Properties such as soil particle size and composition, soil moisture, frequency and intensity of exposure to foot and vehicular traffic and associated degrees of compaction, entrenchment or incision, soil slope and aspect, vegetation presence or absence, species composition, short- and long-term climate patterns, area accessibility, land designations, and environmental compliance can all affect restoration activities.

Generally speaking, however, the higher the UVR class, the more complex and difficult site restoration will be. The NPS is currently developing a programmatic environmental assessment in compliance with the National Environmental Policy Act that describes, in detail, a wide range of restoration activities that may be utilized (pending a final finding of no significant impact) to restore UVR-impacted areas. The NPS is also developing a programmatic agreement that, if completed, will satisfy restoration compliance requirements under the National Historic Preservation Act. These documents complement this report and collectively constitute a coordinated interagency restoration response effort. Restoration activities are anticipated to commence in earnest during 2014.

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Appendix A: Mileages for UVR Class 3: Pre-existing–Used and Wash Classes

Table A-1. UVR Class 3 Pre-existing–Used and Wash mileages.

	Agency		
UVR class	**CPNWR**	**BLM**	**OPCNM**
Pre-existing–Used	9.7	2.6	68.3
Wash	12.1	18.2	34.2

Appendix B: Reference Photos Used to Identify and Classify UVR Features

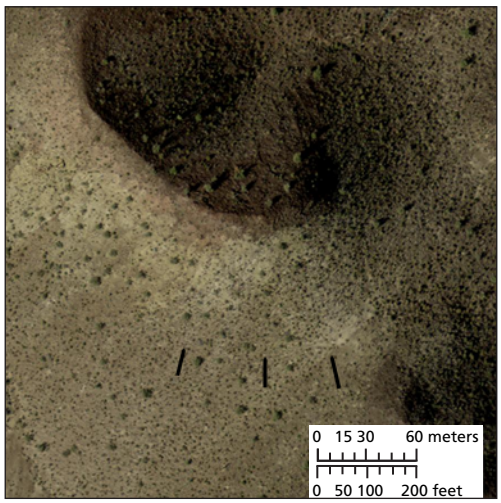
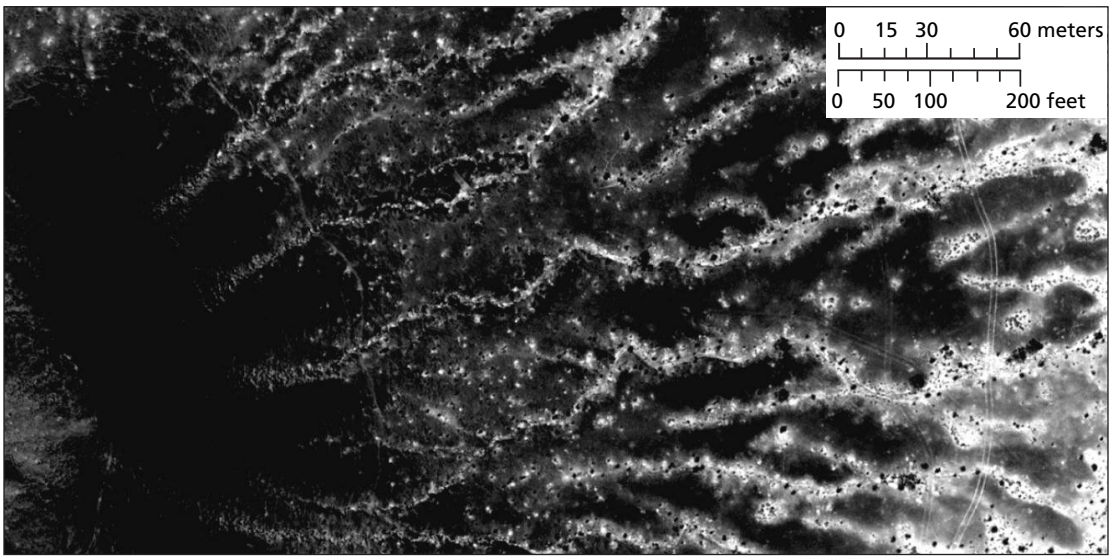


Figure B-1. Landscape features that can mimic vehicle tracks.

Above, several linear features are present on the slope of a volcanic hillside in Cabeza Prieta NWR. These are caused by natural drainage patterns and possibly exposure of a white or lighter-colored caliche (desert cement) layer through erosional processes.

Below, several vehicle tracks, probably less than five years old, are visible at far right of photo. Compare these to the linear features on the far left. These represent junctions between substrate layers, oriented from photo bottom to photo top, caused by erosional processes. Northern Pinacate lava field, Cabeza Prieta NWR.



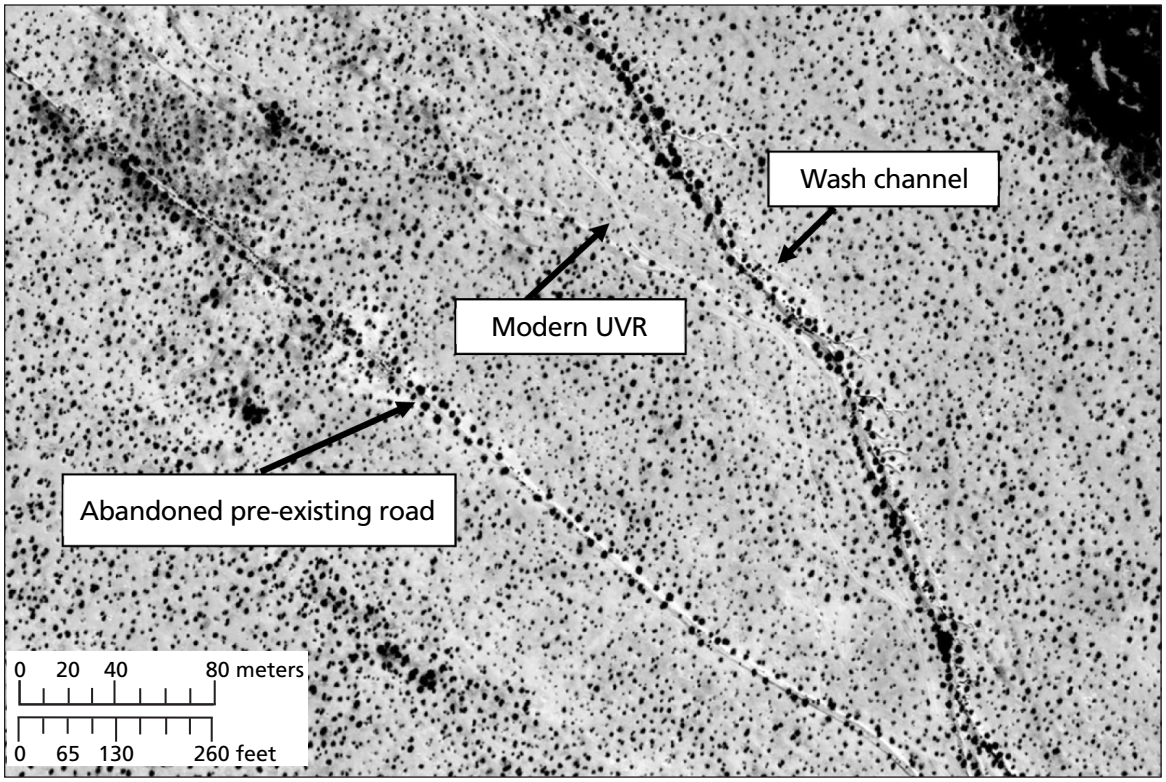


Figure B-2. Abandoned pre-existing road, in center of photo, adjacent to a modern UVR and an active wash system on Cabeza Prieta NWR. Note alignment of perennial shrubs and trees with roadway, and especially artificial straightness in comparison with natural wash channel on photo right.

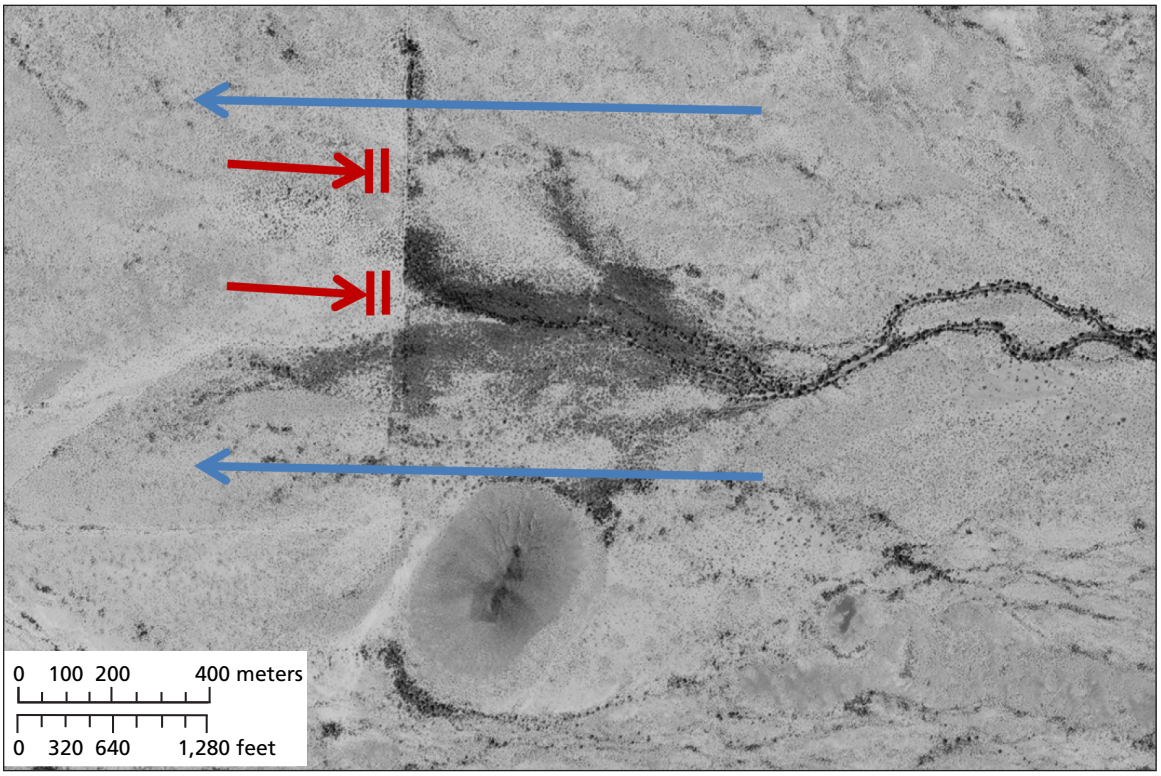


Figure B-3. Hydrological changes induced from roads that are perpendicular to sheet water flow can be dramatic. Vegetation growth has been enhanced "upstream" of a road along the west boundary of Organ Pipe Cactus NM due to water capture behind the road berm and has apparently starved some "downstream" areas of surface water by diverting water along the road rather than spreading it into a broader area. Blue and red arrows represent normal direction of water flow and blockages, respectively.

Appendix C: Interobserver Agreement

We assessed interobserver agreement in detecting and classifying vehicle features to guide the process of integrating CPNWR draft data into the final UVR map (see Methods). We used R vers. 2.13.0 (R Core Development Team 2011) to compute kappa values. Below, we summarize the three main tests and their results used in this process. Kappa values are reported for overall interobserver agreement; contingency tables shown below only include the most common rating from team members compared to the features being tested.

These results only address within- and between-group agreement on the digitizing process; therefore, they should not be considered a measure of accuracy in the UVR mapping process (see Appendix D for ground-truthing results).

Table C-1. Interobserver agreement on vehicle feature detection and classification for draft digitized Class 2 CPNWR data.

		OPCNM observer*		
	Class	**1**	**2**	**3**
CPNWR observer	**1**	-	-	-
	2	37	5	2
	3	-	-	-

Contingency table for draft digitized feature class compared to most common class assigned by OPCNM team members (*n*=44 features identified as vehicle features). In the case of ties, the tie was broken by the more experienced team member(s).

*Number of classifications (*n*=44) identified as Class 1, 2, or 3 by OPCNM observers based on data identified as Class 2 by CPNWR observers.

Table C-2. Interobserver agreement on overall feature detection rates (i.e., completeness of map) for draft digitized CPNWR data.

OPCNM observer recommendations	**Number of times line parts were recommended for addition/subtraction (*n*=50)**				
	0	**1**	**2**	**3**	**5**
Additions	42	3	3	1	1
Subtractions	47	1	2	0	0

Contingency table for how many line parts team members would add or subtract to complete the map (based on most common rating). In the case of ties, the tie was broken by the more experienced team member(s).

Test 1

When team members were asked to identify if a feature was created by a vehicle, there was 78% agreement in the affirmative. When asked to classify vehicle features from Class 1 to 4, Fleiss's kappa rating was 0.556. Fifty features were randomly selected for evaluation; of those 50, six were non-vehicle, and all six non-vehicle features were consistently and properly identified by OPCNM staff as being non-vehicle. Class 2 CPNWR features (which were split in the final classification system into Class 1 and 2) were predominant in the dataset and thus were the only features from CPNWR selected for comparison (Table C-1).

Test 2

When team members were asked to assess the completeness of the map (i.e., were all vehicle features in view mapped?), Fleiss's kappa rating was 0.548 (*n*=50). It was more frequent for team members to recommend addition of line parts than subtraction, suggesting that vehicle features were missed in the draft data more often than they were falsely identified (Table C-2).

Test 3

We also tested team members on a subset of UVR features to assess the assumption that agreement rates on vehicle feature detection and classification should be higher for UVRs experiencing high vehicle use due to their increased visibility on the landscape. When asked to identify if these features were created by a vehicle, there was 97% agreement in the affirmative. When asked to classify vehicle features as Class 1–3 (Class 4 was excluded because these impacts tended to be so much larger and readily distinguishable), Fleiss's kappa rating was 0.634 (Table C-3). Two of the original 30 data points were removed due to errors.

Discussion

There was generally good team agreement on vehicle feature detection. However, the views of OPCNM team members differed substantially relative to feature classification, both within the OPCNM group and in comparison to the status of draft CPNWR data. Given the lower agreement values on how to classify the draft data, we used a manual review process to reaffirm the classification of all UVRs, followed by a final classification review made by a sole expert team member. We also used these test results to train and re-assess team members in standard data-collection procedures.

Digitizers were rated on whether they tended to score higher or lower than other team members, and differences were found. Some team members consistently rated features higher (worse) than average. However, this proved advantageous because higher-rated features were re-visited in the final review for inclusion or exclusion, as opposed to features rated in Class 1, which were not re-visited.

Several landscape features can mimic vehicular routes or tracks. Features falsely identified in draft data as vehicle features in this assessment, in decreasing order of frequency, included: foot trails, livestock trails, junctions between sedimentary or geologic layers in bedrock or conglomerate substrates, and debris/rock flows. With the exception of foot and possibly livestock trails, digitizers can be easily trained to recognize non-vehicle landscape features. The former can be more difficult to differentiate, requiring assessment of average trail width (narrower trails are more likely to be foot trails) and line-feature curvature (vehicle tracks edges have a more regular geometry than foot trails, which have rougher edges [Kaiser et al. 2004]).

It should also be noted that foot trails and vehicle routes often overlapped or were a combination of the two traffic types; in this assessment, such a route type would have been classified as a UVR if any vehicle presence was noted. In addition, as photo resolution decreases, foot trails may become indistinguishable from vehicle tracks. In this assessment, we could detect foot trails on the 2010 1-m NAIP imagery, but they were more easily distinguished from vehicle tracks on the higher-resolution, 30-cm 2008 imagery.

Photographic guides proved useful for team-member training, as well as on-the-ground comparisons with known UVRs. For future work, we also suggest performing regular re-assessments of agreement rates between digitizers to further standardize the mapping process.

Table C-3. Interobserver agreement on vehicle vs. non-vehicle feature detection and classification for Class 3–4 draft digitized CPNWR data (i.e., the most heavily used UVRs; *n* = 28).

		OPCNM observer*			
	Class	**1**	**2**	**3**	**4**
CPNWR observer	**1**	-	-	-	-
	2	-	-	-	-
	3	2	5	17	-
	4	0	0	4	-

*Number of classifications (*n*=28) identified as Class 1, 2, or 3 by OPCNM observers based on data identified as Class 3 or 4 by CPNWR observers.

Appendix D: Ground-truthing Results

We compared east–west field-transect data from 15 surveys to digitized data to assess false positive and false negative rates (see Methods). Similar to interobserver agreement tests, we assessed intersections between a subset of Class >1 UVR features and digitized data (Table D-1). This was done to assess the assumption that agreement rates should be higher for UVRs experiencing high vehicle use than for the entire dataset, which included Class 1 features.

Several survey areas had high false positive rates. This error may be due not only to actual false positive errors (defined as features falsely identified as vehicle features) committed by digitizers, but also to fundamental differences between ground and aerial UVR detectability rates. Areas with high false positive rates (e.g., Mohawk Valley) may be partially explained by field observer or field data errors (missing data), lower UVR detectability on the ground than in an aerial photograph, or by an actual false positive error. During this project, we noted that preexisting roads were sometimes more easily detected in aerial images than on the ground by the presence of a long, artificially straight, and linear arrangement of vegetation, which may be less apparent from a ground view. We re-examined the imagery in areas with high false positive rates and found clear examples of UVRs that went undetected (or perhaps merely unrecorded) by ground observers. Lower ground detectability of UVRs may also occur in areas that experience high surface flows, where vehicle tracks become partially or totally obscured by natural erosion processes (Hereford 2009). The vast majority of the project area has a very low vegetation density (often <5% perennial plant cover); therefore, vegetation-obscuring UVRs did not seem to be a reasonable explanation for why ground observers detected fewer UVRs

Table D-1. Results of ground-truthing digitized UVR features and percent matching of Class >1 digitized features with east–west field transect data, CPNWR and OPCNM, 2008.

Survey number	General survey area	False positive rate	False negative rate	Percent presence/absence agreement	
				Overall	Class >1*
Cabeza Prieta NWR					
1	Northwestern CPNWR	0.0	73.6	26.4	100.0
2	Northwestern CPNWR	2.6	58.2	39.2	100.0
3	Lechuguilla Desert	54.8	8.7	36.5	NA
4	Lechuguilla Desert	19.8	22.0	58.2	100.0
5	Lechuguilla Desert	13.6	28.4	58.0	100.0
6	Mohawk, San Cristobal, Growler Valleys	50.7	20.5	28.8	66.7
7	Middle Growler Valley	42.3	29.3	28.4	100.0
8	Northern Growler Valley	0.0	51.7	48.3	NA
9	Southern Growler Valley	10.8	36.5	52.7	100.0
Organ Pipe Cactus NM					
10	Southeastern OPCNM	41.4	39.7	18.9	100.0
11	Valley of the Ajo	34.9	44.2	20.9	NA
12	Lukeville	18.9	59.5	21.6	50.0
13	Northeastern OPCNM	19.0	47.6	33.4	NA
14	Northwestern OPCNM	10.5	56.2	33.3	88.9
15	La Abra Plain	13.3	76.7	10.0	NA
Average		**22.2**	**43.5**	**34.3**	**90.6**

*Class >1 percent agreement was only calculated for surveys that had >1 intersection between digitized features and field transect data; NA indicates there were either 0 or only 1 intersection.

in some areas. The potential false positive errors committed by digitizers may have been due to some landscape features or foot trails that mimicked UVRs (see Appendix C, examples in Appendix B).

Areas with high false negative rates (e.g., northwestern CPNWR) were most likely caused by low aerial UVR detectability in areas with low color contrast between soil surface and subsurface. It is also possible that high false negative rates were caused by ground observers' falsely identifying non-vehicle features as vehicle features. However, this seems unlikely, given that vehicle tracks of modern origin are quite distinct when viewed on the ground.

Including UVR Classes 2 through 4, features generally yielded good-to-excellent agreement rates between ground-observer and digitized data (Table D-1). This supported the hypothesis that UVRs experiencing higher use were more easily detected and classified by both observer groups.

We also compared road surveys to digitized data to assess false positive and false negative rates (Table D-2). These error rates were lower and less variable than those of the east–west transects. In both ground-truthing survey types, false negative rates were generally greater than false positives.

The highest false negative rate occurred on State Route 85, which is not surprising, given that field crews had to maintain higher driving speeds for safety reasons, but does highlight how UVRs can easily be missed even by experienced observers. Most (>70%) of the features missed by digitizers were in the 'Wash' class; these are apparently not easily detected by digitizers.

In contrast, class agreement was often low and quite variable between field data and digitizers. For most (>70%) of the class disagreements, field observers rated features in a lower class than digitizers.

Observer fatigue, on the part of both digitizers and ground observers, likely plays an important role in detection rates. Neither inter- nor intra-observer variability on UVR detection during ground surveys is well-known, but may also contribute to the differences noted in this project between the ground and digitized data.

Table D-2. Results of ground-truthing digitized UVR features with 2011 road transect data, OPCNM.

Survey (Road) name	False positive rate	False negative rate	Percent agreement (Class >1)	
			Presence/absence	Class
Ajo Mountain Loop	0.0	0.0	100.0	20.0
Armenta	0.0	25.0	75.0	75.0
Bates Well	0.0	13.6	86.4	31.6
Camino Dos Republicas	16.7	0.0	83.3	40.0
East Fenceline	1.9	14.8	83.3	53.3
East Fenceline-West of Lukeville	0.0	12.5	87.5	100.0
North Boundary	0.0	0.0	100.0	0.0
North Puerto Blanco	0.0	33.3	66.7	71.4
Pozo Nuevo	3.2	9.7	87.1	44.4
South Puerto Blanco	4.4	22.2	73.4	45.4
State Route 85	2.7	43.2	54.1	35.0
West Boundary	0.0	0.0	100.0	80.0
Quitobaquito West	4.5	22.7	72.8	68.8
Average	**2.6**	**15.2**	**82.3**	**51.1**

Percent agreement for presence/absence and class are measures of how often field crews agreed with digitizers on UVR presence/absence and class, respectively.

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