

Where to start? A new citizen science, remote sensing approach to map recreational disturbance and other degraded areas for restoration planning

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This UN Decade on Ecosystem Restoration highlights the capacity of restoration to mitigate trends in biodiversity loss and land degradation. However, many managers lack the tools they need to systematically and comprehensively identify degraded sites to prioritize restoration efforts given limited resources. We developed a novel, inexpensive, low-tech approach for training and engaging citizen scientists to identify recreational impacts and other degraded areas within a defined unforested area. The mapping process follows four phases: (1) Landscape scans by citizen scientists using Google Earth Pro imagery; (2) A second scan of all marked sites based on high resolution aerial photography; (3) Compilation of basic information about the degraded sites; (4) Addition of associated soil type and plant communities. In the 12,375 ha McDowell Sonoran Preserve (Scottsdale, Arizona), we detected 67 new sites not previously identified by land managers, using an estimated 305 citizen scientist hours and only 30 staff hours. Each site has accompanying information including distance from nearest access point, cause of degradation, and plant and soils detail. After completion, we conducted independent field visits of 33% of the detected sites and verified degradation in all cases. We found that the remotely sensed approach provided better perspective to accurately measure the scale and original source of degradation compared with field visits. The approach can be conducted over a short period of time using citizen scientists, allows managers to undertake landscape level restoration prioritization and planning, and, if repeated, can be used to monitor changes in degradation and restoration over time.

Key words: arid lands, citizen science, Google Earth, priority setting, remote sensing, restoration planning

Implications for practice

- The method accurately and systematically identifies areas with bare ground or severely reduced vegetative cover and unauthorized recreation trails in ecosystems not obscured by dense forest cover.
- It can accurately identify smaller sites (to 100 m²) than most currently available approaches.
- This approach supports restoration planning, including setting priorities across a complete set of degraded sites and selecting site-appropriate plant species. If repeated, it can be used to monitor degradation or regeneration over time.
- This field-verified, inexpensive, and low-tech approach can be accomplished through citizen science, using public information and common Geographic Information System tools.
- Aerial assessment of the size, shape, and cause of degraded areas tend to be more accurate and efficient than ground surveys.

Salmon 2015), ecological restoration is seen as an important pathway to restore and sustain biodiversity, ecosystem services, and related benefits (Gann et al. 2019). However, in a recent meta-analysis of 400 studies worldwide documenting recovery from large-scale disturbances, authors found that, on balance, active restoration did not speed up the process or result in more complete recovery than natural recovery after removing the disturbance (Jones et al. 2018). This emphasizes the need for a careful assessment process to evaluate which areas should be allowed to recover simply by removing ongoing disturbance and which areas need additional inputs. This kind of planning

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Introduction

Amid a crisis of biodiversity loss (Ceballos et al. 2015) and estimates of degraded lands between 1 and 7 B ha (Gibbs &

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is aided by landscape level planning tools such as maps of degraded areas, sizes, and cause of disturbance (Clewell et al. 2005; CBD Secretariat and Society for Ecological Restoration 2019). However, restoration primers either do not provide guidance on how to map areas in need of restoration (Clewell et al. 2005) or suggest a combination of expert knowledge and mapping (CBD Secretariat and Society for Ecological Restoration 2019). Currently, land managers in the northern Sonoran Desert gather and map degraded sites as information becomes available, rather than on a systematic basis (Personal communication with regional land managers, McDowell Sonoran Preserve, Phoenix Preserves, Maricopa Regional Parks, 2020) which may lead to incomplete information of degraded areas. This, in turn, may lead to expending limited resources on restoration sites that may not be highest priority, given full knowledge of all sites. The lack of such information also impedes the ability to track natural regeneration of these sites over time.

Researchers have developed methods to apply remote sensing to identify and quantify land degradation at the regional to global scale, for national and regional land use planning and to meet international sustainable development goals and biodiversity targets (Dubovyk 2017; Dong et al. 2019). These large-scale assessments use satellite imagery to detect land conditions and changes over time, including the conversion of natural open space to agricultural use or urban development (Jantakat et al. 2019; Gupta & Sharma 2020) and to track large scale recovery (Ghaffarian et al. 2020). These techniques typically use land-use/land-cover classifications (Xun & Wang 2015; Dubovyk 2017; Jantakat et al. 2019; Ghaffarian et al. 2020; Gupta & Sharma 2020) or normalized difference vegetation index (NDVI) (Higginbottom & Symeonakis 2014; Reeves & Baggett 2014) to assess change.

More sophisticated approaches are developed continually. Conservation International recently launched a database called Trends.Earth that maps degradation as changes in land productivity (using changes in NDVI, Rain Use Efficiency, residual trend, and water use efficiency) and land cover (using changes in land cover) across the globe using satellite data. This effort represents a step-change in measuring these trends consistently and supports reporting for national and international targets (Trends.Earth 2018). The Rangeland Analysis Platform uses multiple, large training databases to improve the accuracy of ground cover estimates including bare ground (Allred et al. 2021). Increasingly, scientists are also employing remote sensing for monitoring restoration outcomes, as resolution and access to the technology improves (e.g., Reif & Theel 2017). The recent development of Google Earth Engine has drastically improved access for all of this work by providing free satellite images and a platform for advanced analysis techniques. However, while the access, resolution, and tools for large-scale landscape evaluation continue to improve, the processing is complex, requires advanced training not readily available to many land managers, and generally has insufficient resolution to identify the smaller-scale degraded areas associated with, e.g., inappropriate recreational use. However, attempts are being made to create simpler approaches with higher resolution (Lee et al. 2018).

Increasingly, professionals have recognized volunteer citizen scientists as valuable and often essential assistants in conducting scientific work (Silvertown 2009; Henderson 2012). Not only are citizen scientists a source of labor, but many also have useful computational or managerial skills, and involving them can further the outreach and education goals of many projects (Silvertown 2009; Henderson 2012). However, in order to ensure high-quality work from volunteers, project leaders must provide appropriate motivation and oversight including explicit objectives, well-documented protocols, ample training, and adequate review and feedback (Silvertown 2009). Because committed volunteers produce higher quality data (Nerbonne & Nelson 2008), they should be used for more than just data collection and also participate in analyzing and reporting results (Henderson 2012).

Because of the demonstrated ability of trained citizen scientists to do high-quality work with proper supervision, we developed and tested a method that utilizes them to address the need for low-cost identification of small-scale degradation for restoration planning. This novel, citizen science approach is designed to comprehensively identify recreational impacts such as trail widening or spider trails and degraded areas with little or no vegetation at a landscape level in natural, open spaces without dense tree cover. It should be noted that this technique cannot identify plant community shifts associated with degradation such as shrub encroachment or grazing damage. The approach uses free public and other generally available imagery, including Google Earth resources, common GIS software, and public ecological resources.

Methods

Study Area

Our team of citizen scientists scanned the entire 12,375 ha of the McDowell Sonoran Preserve (Preserve), Scottsdale, AZ, U.S.A. from March to August, 2018. The Preserve is located in the extreme northeast of the Sonoran Desert in the Arizona Upland region (Fig. 1). The southern portion of the Preserve is mountainous and there are isolated mountains in the northern area. Elevations range from 515 to 1,529 m, and excluding peaks the northern area is generally 200–300 m higher than the southern area. Rainfall varies across the Preserve, ranging from approximately 200 mm/year in the southwestern area closest to Phoenix to approximately 300 mm/year in the furthest northeastern area. There are 14 biotic communities in the Preserve (Jones & Hull 2014), most in the Tropical-subtropical desertlands paloverde—mixed cacti series (Brown et al. 1979) with small areas of Warm temperate scrublands and Warm temperate grasslands.

Restoration Scanning Process

We developed and tested a new approach for training citizen scientists to identify degraded sites within defined boundaries. For the purpose of detection, we defined degraded areas as sites at least 100 m² with severely reduced vegetative cover, bare ground, or human-caused unauthorized trails or trail clusters. This definition does not provide differentiation between recently disturbed areas that may recover on their own and degraded

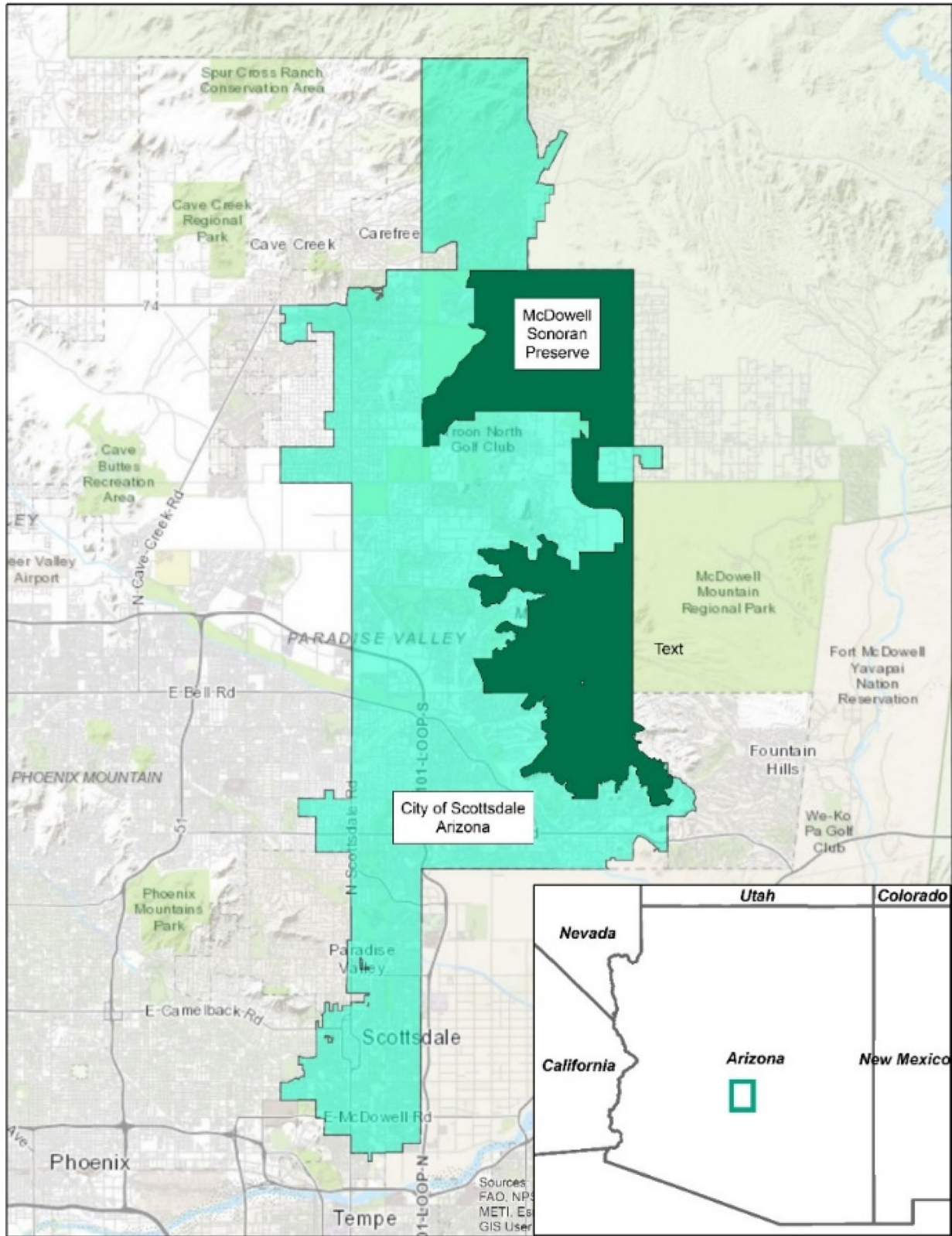


Figure 1. Locator map of the McDowell Sonoran Preserve, Scottsdale, AZ, U.S.A.

areas that may not, thus subsequent field visits will be necessary for restoration planning. This citizen science restoration scanning process (hereafter CSRScan) can be described in four phases.

Phase 1: Google Earth Scan

For phase 1 scanning, we used Google Earth Pro (GE), which had an estimated average resolution of 15–50 cm/pixel depending on location. To avoid misidentification of trails or washes as degraded areas or duplicative identification of known degraded areas, spatial data from the City of Scottsdale (CoS), the McDowell Sonoran Conservancy (the Conservancy, Scottsdale, AZ, U.S.A.), and the Arizona Department of Water Resources (ADWR) were added to both GE and to an ArcGIS map (ESRI, 2016, ArcGIS Version 10.6. Environmental Systems Research Institute, Redlands, CA, U.S.A.) prior to scanning that showed the following attributes:

Preserve trails and service roads (both active and closed); sites previously identified as degraded; previous restoration sites; the centerline or boundary of water features including washes as defined by the ADWR 2001 10-ft countywide mapping project; and constructed features (e.g. trailheads, equipment yards).

To prepare GE for citizen scientist scanning efforts, we added the Preserve boundary and a square grid of cells 200 m on each side, which helped citizen scientists focus their scanning efforts. We also divided the Preserve into 20 sections from north to south, each approximately 1 km in north–south direction and extending over the entire width of the Preserve, for an average of roughly 600 ha per section.

We recruited and provided specialized training for citizen scientists from our pool of volunteers who had already received basic training in the Conservancy organization and scientific techniques (Fig. 2). A citizen science lead for the project was selected who has led many previous citizen science projects, but is not a formally trained scientist. He worked with

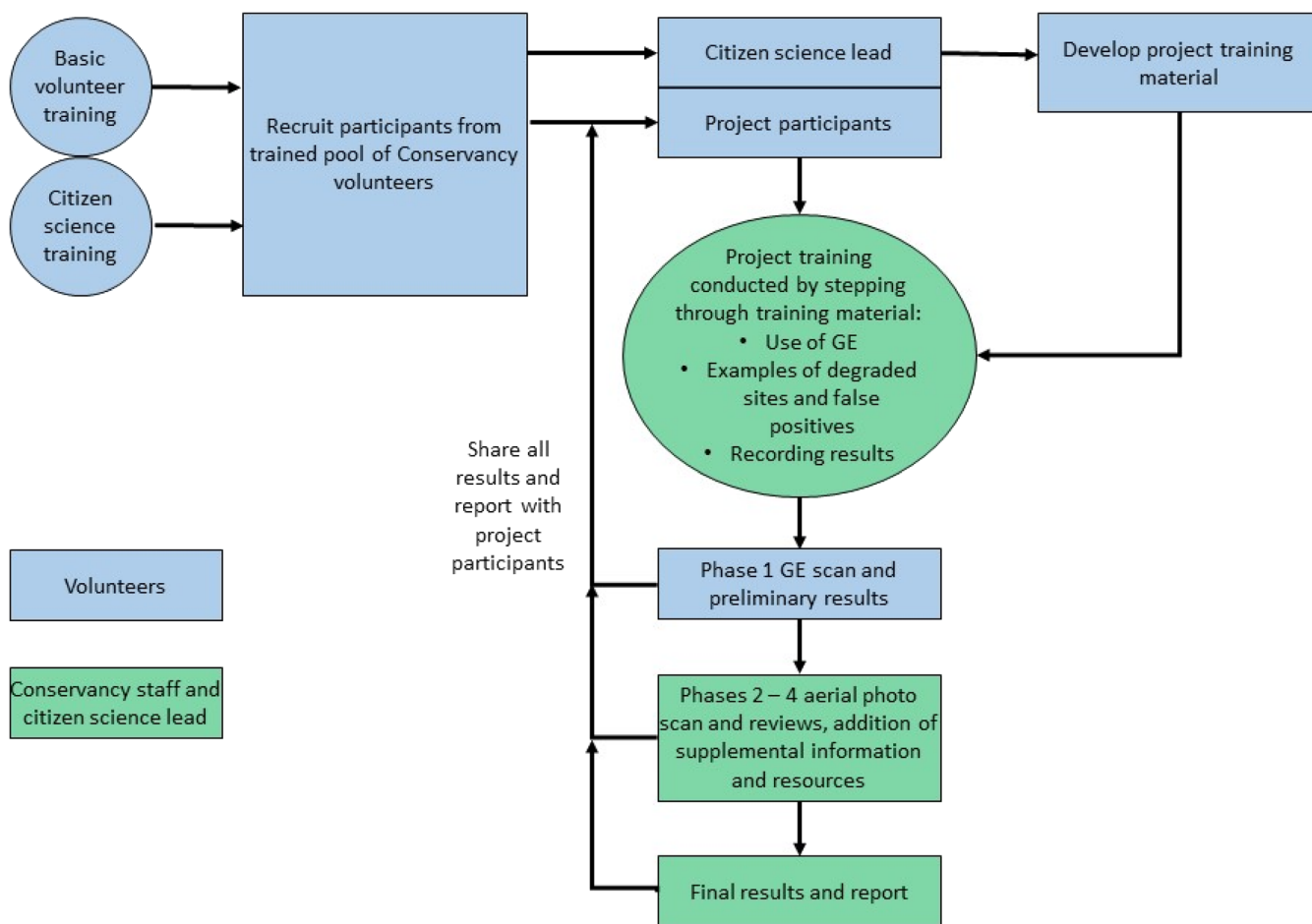


Figure 2. Citizen science volunteer involvement in CSRScan process. Citizen science research led by staff scientists has been part of the mission of the McDowell Sonoran Conservancy (Conservancy) for over a decade. The Conservancy trains volunteers to work on multiple citizen science projects (upper left circles) and participants were recruited from this pool of volunteers. During project training, the citizen science lead executed the instructions step-by-step on a projected screen on Google Earth (GE) while participants replicated the process independently on their computers. We defined their task as marking areas that were at least 100 m² in extent with no or limited vegetation and human-caused rather than animal-caused or natural features. To reinforce that, we viewed examples of possible degraded sites (e.g. unauthorized trails) and natural features (e.g. wildlife trails) that could be confused with degraded sites on GE. Following training, participants worked in parallel to scan assigned portions of the Preserve using the same protocol, forwarding their results to the citizen science lead at the end of Phase 1 (middle blue box). A key feedback in the process is to share results back with participants to foster ongoing volunteer engagement (middle up arrows).

Table 1. Approximate time spent by citizen scientists and staff for each CSRSscan phase of the project completed for the 12,375 ha McDowell Sonoran Preserve, Scottsdale, AZ, U.S.A. “Protocol and training preparation” material is available upon request.

<i>CSRSscan phase</i>	<i>Citizen scientist time (hours)</i>	<i>Citizen scientist lead time (hours)</i>	<i>Staff time (hours)</i>	<i>Total time (hours)</i>
Protocol and training preparation		40	10	50
Citizen scientist training	20	5		25
Phase 1: Citizen scientist remote sensing scan	100		-	100
Phase 2: Scanning reviews		50	10	60
Phase 3: Associated degraded area reference table		20	-	20
Phase 4: Additional restoration resources: plants and soils		40	10	50
Total hours	120	155	30	305

Conservancy staff to create the scanning protocol and develop the training material (Table 1).

Citizen scientists received live, 2-hour training sessions in which the citizen scientist lead demonstrated the process to the project team through a live session using GE in which participants followed along on their own computers (Fig. 2). We also provided a detailed instruction manual with illustrations for reference. During the training, the citizen science lead showed how to scan assigned sections on GE at a scale of about 2.5 cm on screen equaling 25 m on the ground (i.e. at a scale of roughly 1:1,000). Citizen scientists were instructed to mark (with GE points, called “placemarks,” or polygons) areas at least 100 m² in extent with no or limited vegetation and human-caused rather than animal-caused or natural features (see Fig. 3 for examples). We taught citizen scientists to distinguish animal use-trail clusters, which tend to be faint and random in direction, from trail clusters caused by human activity, which tend to be better defined, more linear, longer, and often have a rationale (e.g. a shortcut) or a destination (e.g. connection with an official trail) (see Fig. 3B for an example of a human caused trail cluster). In an effort to ensure degraded sites were not missed, each section was scanned independently by two different citizen scientists, and they were instructed to mark locations even when in doubt or when sites did not meet all the specified criteria.

The 14 citizen scientists engaged on this project spent approximately 2 hours on each area depending on its size and the number of candidate sites identified, and the initial scans were completed in about 100 hours of citizen scientist time (Table 1). The 376 distinct candidate sites identified in this initial scan were saved as KMZ files and sent to the citizen scientist lead. The citizen scientist lead compiled and reviewed the sites on GE to confirm alignment with stated criteria and removed false positives. The remaining 75 candidate sites were transferred to ArcGIS Online (AGOL) and ArcMap 10.6. The most common false positives were washes and animal use trails. Washes or wash extensions that had developed since the 2001 data provided by ADWR were identified by bands of denser vegetation extending from previously identified washes along topographical drainages.

Phase 2: Aerial Photography Review

In phase 2, the remaining sites were examined on ArcMap 10.6 by the citizen scientist lead using 10 cm/pixel aerial imagery

taken during late 2017 and early 2018. The superior resolution available in this review resulted in elimination of some previously identified sites based on stated criteria, adjustment of the sizes and shapes of some identified areas, and, in a few cases, addition of sites revealed in the higher-resolution aerial imagery. Four degraded junctions between 50 and 100 m² (below the minimum size requirement) were retained because disturbance has not stopped in these areas and thus they are likely to increase in size over time. The second round of review took approximately 50 hours (Table 1) and resulted in a draft final list of 51 degraded sites, which were converted to polygons showing the approximate impacted area.

A final review was performed using AGOL and the high-resolution aerial imagery by the staff project leader, who was provided with both the 75 candidate degraded sites and the 51 proposed final sites. After reviewing the candidate sites, discussion between the staff and citizen scientist leads, and field examination of a few easily reached locations, a final list of 67 degraded sites was developed. This concluding review took less than 10 hours (Table 1).

Phase 3: Reference Tables

In phase 3, using information from ArcMap, we developed a reference table to summarize information on the identified degraded sites useful for later priority-setting activities, including area, distance to the nearest access (official trail, official service road, or paved road), and disturbance type. The types of disturbance on the Preserve were categorized as follows:

- (1) Unauthorized trail cluster, that is, several use trails in a compact area. These were most common near boundaries with developed areas or as shortcuts between existing trails or service roads.
- (2) Areas adjacent to trails, such as large local bare areas of trail widening.
- (3) Widening at trail or service road junctions, where the junctions widened into large bare triangles due to short-cutting.
- (4) Previously impacted areas, such as old prospecting sites and closed areas where disturbance has stopped, but the site has not recovered.
- (5) Other types describing specific situations like scenic view areas where disturbance has not stopped.

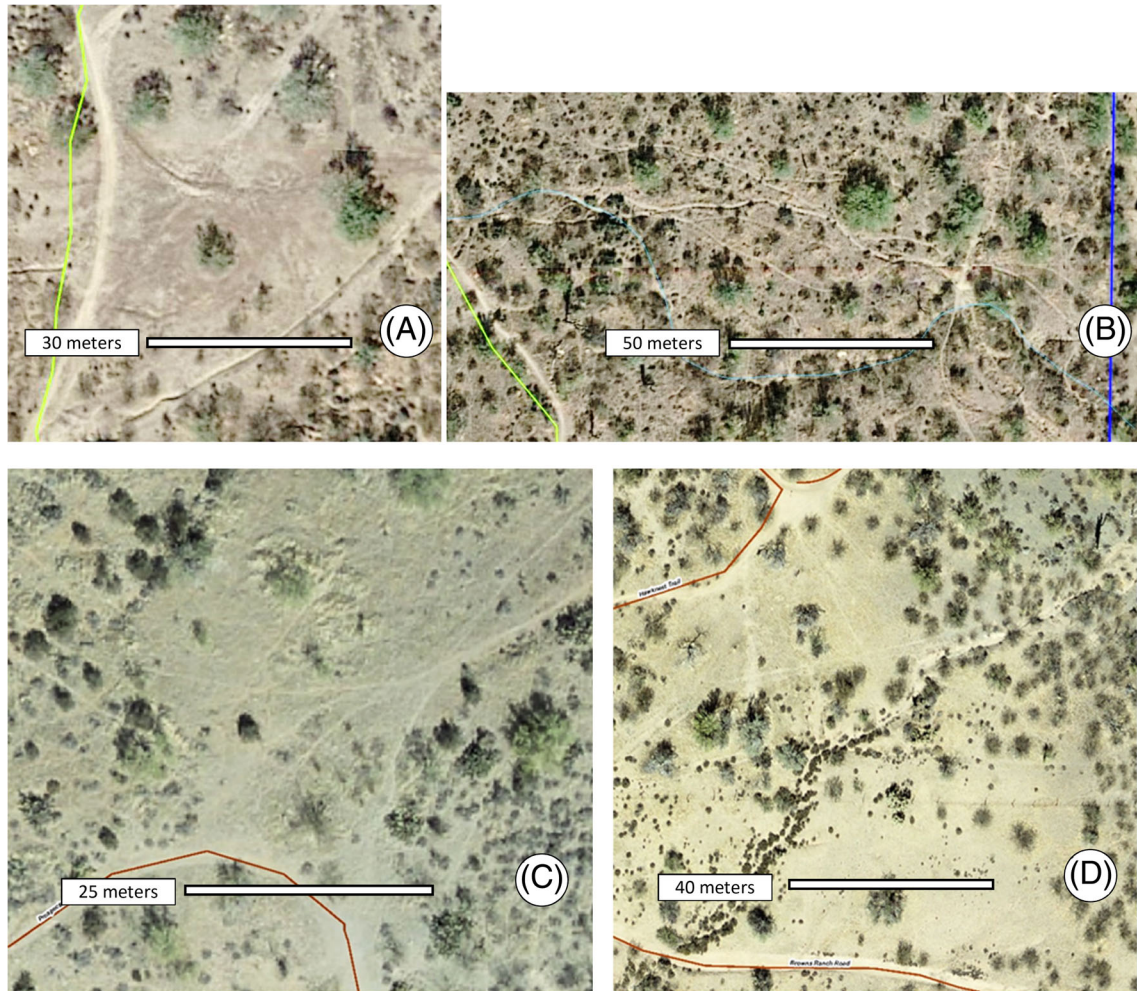


Figure 3. Examples of degraded areas as viewed on Google Earth as follows: (A) Unauthorized trail adjacent to existing trail. (B) Unauthorized human trail cluster connecting neighborhood outside Preserve boundary to existing trail. (C) Junction of existing trail and abandoned road. (D) Degraded area between existing trails. Scale varies as shown. The light green (A, B) and red (C, D) lines are authorized trails and the blue line (B) is the Preserve boundary.

Phase 4: Additional Restoration Resources: Plant and Soils

The USDA Natural Resources Conservation Service (USDA NRCS) Web Soil Survey (WSS) provides Ecological Site Descriptions (ESDs) across most of the United States that can be helpful in identifying the native species associated with the soil type of a specific area (Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture 2018). To access this information, we established an “area of interest” that covered the Preserve, then generated a soil map for that area and included it as a layer in the restoration map (Fig. 3). On the ArcMap, AGOL, or GE map of the area scanned for degraded sites, one can zoom to a specific degraded site, observe the map unit(s) of the local soil, and then download an ESD associated with the specific soil type. Each ESD document includes a state and transition model that describes the general impact on local species of ecological transitions such as the introduction of exotic species or degradation followed by extended recovery and provides a list of plant species in the potential plant community generally associated with the

particular soil type of the ESD, listed as the “historical climax plant community” (Natural Resources Conservation Service, United States Department of Agriculture 2021). These species lists can provide the basis for deciding what seed mix or transplants are most appropriate in restoration of a specific degraded site. However, because the plant communities listed in the ESDs are generalized with soil type and not specific to any particular location, we refined these by comparing them with the native flora list for the Preserve (McDowell Sonoran Conservancy 2014). The U.S. Geologic Survey (USGS) has developed a restoration priority list of Sonoran Desert plant species (T. Esque 2018, personal communication). This sheet is useful for choosing species with particular habitat benefits to wildlife and pollinators and for identifying species that may be easier to propagate. Note that since more than one soil type and associated plant community may exist at each site, we recommend site visits to verify soil type(s) and refine a suitable plant list. The creation of the soil map and assembling Excel sheets for each ESD type to compare the potential plant community species,

local native flora list, and the USGS priority list required about 50 hours of staff and citizen scientist time (Table 1).

Field Comparison

In November 2020, teams conducted independent, in-person field surveys of 22 of the 67 sites for two purposes: (1) verify whether sites identified as degraded in the CSRScans were degraded when observed on the ground; (2) compare the accuracy in estimating degraded site size and type of disturbance between the CSRScans and the field survey. We chose sites using a stratified random approach weighted by the number of degraded sites within three sections of the Preserve. Citizen scientists were trained to collect simple information about the site: (1) measure the area of the site and (2) describe the disturbance type (area adjacent to trail, trail junction, trail cluster, old impacted area, other). The teams were “blind,” that is, to keep the verification results independent, they were not given the results of the 2018 remote sensing scans. We provided detailed illustrated instructions, an in-field training at an actual degraded site, and maps and centroid coordinates for each of the verification sites.

Disturbance size was measured in at least one of two ways, using the “Area Calculation” function on a handheld Garmin GPS unit and/or using the polygon feature of the ESRI ArcGIS Collector app. The two measurement approaches were used

because not all teams had GPS units and in case of difficulty using either measurement function. Both measurements were collected and reported as means for 19 of the 22 sites and in all but two cases the measurements were within 10% of each other (Table 2). In one of the two outliers, the two measurements differed by 25% but bracketed the CSRScan result. In the other case, the two results differed by 17% and both were substantially less than the scanned result. The teams were instructed to be conservative in the area measurements and limit the site perimeter to include only visibly degraded areas (e.g. human-caused tracks) or areas with substantially less or different vegetation than outside the selected perimeter.

Once the field surveys were completed, we used ArcMap to directly compare area measurement polygons and type of disturbance category from the field survey with CSRScan results, using the same 2017–2018 high-resolution aerial photos used in stage 2.

Results

CSRScan

This project identified 67 previously unknown degraded areas, that is, polygons, 63 of which were at least 100 m² in size (Fig. 4; Table S1). Of the disturbance types categories, 20 were widened areas adjacent to trails, 17 were

Table 2. Field comparison results. Size and type of disturbance as estimated through the remote sensing project and the field verification. The area% difference was calculated by subtracting the remote sensed area from the average of the GPS and Collector app measurements (except for the sites marked with *, indicating only GPS was used) of area and dividing by the remote sensed measurement. Plus sign (“+”) indicates that the verification confirmed the same disturbance type as identified through the remote sensing scan. Degraded types are defined as follows: “previous” indicates previously degraded, not ongoing, “trail” indicates trail widening, “junction” is widened trail junction, and “other” which refers to those that do not fit the other categories and have ongoing disturbance (either “scenic” or “stock tank”).

Site	Area (m ²)			Disturbance type	
	CSRScan	Field survey mean	% Difference	CSRScan	Field survey
25	7,123	340	-95.2	Trail cluster	+
1	1,259	174	-86.2	Trail cluster	Previous
0	11,790	1855	-84.3	Trail cluster	Trail; Previous
12	937	225	-76.0	Previous	+
19	2,932	827	-71.8	Previous	+
40	491	155	-68.4	Junction	Trail
62	2,045	706	-65.5	Previous	+
48	642	227	-64.6	Trail	Previous
50	4,180	1,534	-63.3	Previous	+
24	377	161	-57.3	Trail	+
44	234	105	-55.1	Other: Scenic	Trail
27	341	157	-54.0	Trail	Junction
57	1,151	560	-51.3	Previous	Old roads
28	366	200	-45.4	Previous	+
37	595	455	-23.5	Trail	+
35	428	330	-22.9	Trail	+
41*	208	180	-13.5	Previous	+
7	298	277	-7.0	Trail	+
16	2,442	2,514	2.9	Other: Stock tank	Trail; Previous
4*	4,817	5,700	18.3	Trail cluster	+
14	84	118	40.5	Junction	+
8*	131	254	93.9	Junction	+
Total	42,871	17,054	-60.2		

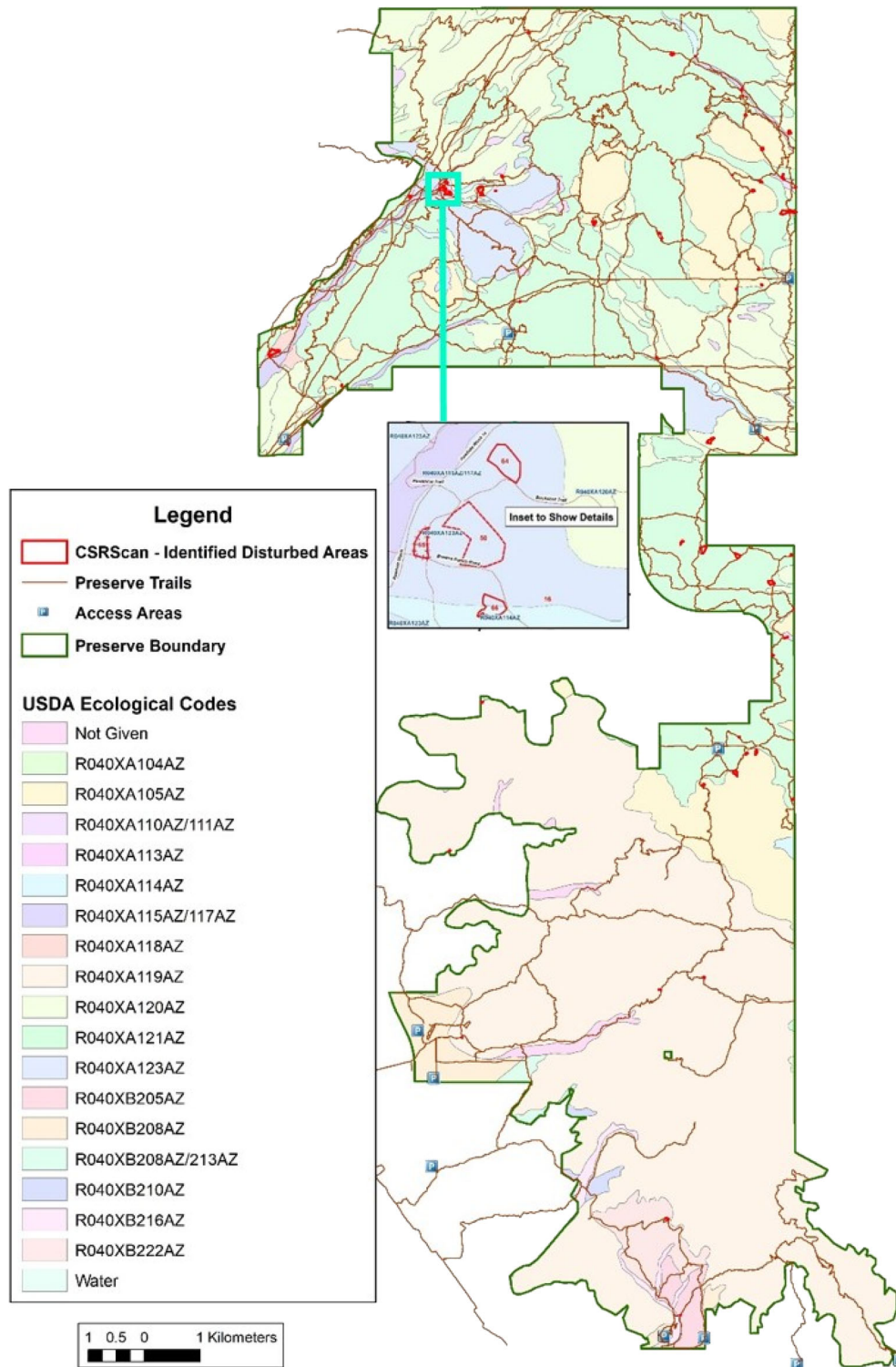


Figure 4. Map of degraded area scan results in the McDowell Sonoran Preserve, Scottsdale, AZ, U.S.A.

previously impacted areas, 13 were widened trail junctions, 9 were unauthorized trail clusters, and 8 were other types of disturbance (Table S1). The entire effort took an estimated 305 hours, with only 10% of that time required by staff (Table 1).

The sites we mapped ranged from 53 to 11,727 m² (Table S1) with a total of 10.5 ha. The previously mapped areas provided by the City of Scottsdale ranged from 184 to 37,609 m² and totaled 18.7 ha, for a cumulative total of 29.2 ha in the Preserve. The previously mapped disturbances

were largely under or adjacent to the high voltage power lines that cross the northern section of the Preserve and in utility rights-of-way.

Field Comparison

We verified that all 22 sampled sites were degraded (Table 2). For the 22 sampled sites, the CSRScan identified 42,871 m² as degraded compared with 17,054 m² through field surveys. The sizes of 18 of the 22 degraded sites were perceived to be over 20% smaller (16) or larger (2) as measured by the field teams compared to the CSRScans. Through the aerial photography review, we confirmed that in all 16 cases where the CSRScans were greater than 20% larger than field surveys, the CSRScan result was more accurate. In these cases, the field teams had not observed the full extent of the degraded sites, likely due to obscured views, that is, vegetation, washes, hilly, or rocky terrain. In the two remaining cases (both trail junctions), field survey polygons encompassed more of the irregular shape compared with quadrilaterals (CSRScan); actual differences were still relatively small (Table 2). The full extent of a number of degraded sites, especially unauthorized trail clusters, was more easily visible using remote sensing than from the ground.

In comparisons of disturbance type category, the field visit results were in agreement with 14 of the 22 (64%) CSRScan observations (Table 2). For the eight cases not in agreement, we reviewed the 2017–2018 high-resolution aerial imagery and found that in seven of the eight cases, the CSRScan results were accurate, but the remaining case was ambiguous. These comparisons illustrate a distinct benefit of identifying and viewing degraded areas using remote sensing rather than trying to discover and measure them from the ground.

Technology Limitations

Google Earth imagery tends to be higher resolution and more frequently updated in or near urban areas, but less available in protected areas (Lesiv et al. 2018). Similarly, reasonably current high-resolution aerial photos generally are available for urban and suburban areas but are less common for rural or isolated areas. These potential information limitations mean that this method generally will provide more detailed and better-defined results in urban or near-urban areas. The resolution of GE imagery can vary by as much as 15 m to 10 cm (Lesiv et al. 2018). It is possible to identify bare dirt areas even in locations where only moderately high-resolution imagery (e.g. 20–50 cm/pixel) is available. However, sometimes aerial photography is available at a higher resolution (commonly 10–25 cm/pixel) through local government agencies who use it to track development or other uses. At the higher resolution, scanners will be able to detect small vegetation not visible at lower resolution and be able to remove false positive tagged sites identified in phase 1 scans. It is also important that recent images are used to ensure scanning represents the current or recent state of an area, rather than identifying sites that have regenerated or missing areas that have been degraded since the imagery was taken. Finally, locations in GE can vary in terms of accuracy due to problems with

georeferencing, but this depends on location (Visser & Both 2005). In our case, the GE locations were accurate as verified through the high-resolution aerial photographs and field surveys.

Discussion

We have developed an inexpensive, citizen science approach to successfully identify degraded sites for landscape level restoration planning. Previous work to detect degraded lands at the landscape scale has involved the use of remote sensing (satellite and aerial imagery) to detect large-scale land use changes through comparisons of land use classifications, NDVI, or other parameters over time (Dubovyk 2017). Similarly, others are using GE for conservation purposes, e.g., assessments of river ecosystem services assessment (Large, Gilvear 2015) and mapping and characterizing limestone hills in Malaysia for prioritization of conservation efforts and long-term monitoring (Liew et al. 2016). Klemas (2013) describes a wide range of remote sensing tools and analysis techniques available for wetland assessments, selecting suitable restoration sites for wetlands, and monitoring restoration success through detection of changes in wetland extent and quality, function, buffers, and other important variables (Klemas 2013). However, these techniques require advanced tools and techniques. The CSRScan approach can be used to identify degraded sites as small as 100 m² in large (approximately 10,000 ha) protected lands with 250–300 hours of work, 90% of which can be performed by citizen scientists without complex processing. If repeated, it can be used to monitor changes in degradation or land uses over time.

The CSRScan process relies on being able to view the ground to identify bare patches in vegetation. Thus, it may be difficult to distinguish between naturally occurring gaps in forest or dense shrub cover and degraded areas. However, others offer approaches for using GE or Microsoft Bing maps to monitor forest canopy change over time to detect degradation or recovery (Ploton et al. 2012; Lesiv et al. 2018) or detect relative abundance of non-native trees in forested systems (Doi & Ranamukhaarachchi 2010). Because the CSRScan focuses on detecting bare ground rather than detecting differences in vegetation as done by more complex remote sensing approaches, our approach may miss some disturbances in which vegetation has vastly changed, e.g., conversion to a different state through invasive species or heavy grazing. The ability to detect invasive species through other remote sensing approaches has made considerable progress, but still have limited area coverage (Unmanned Aerial Vehicles), require proper timing coincident with invasive species phenology, and demand complex processing techniques (Müllerová et al. 2017; Jensen et al. 2020; Papp et al. 2021). The ability to detect land cover change requires acquisition of the correct time series of satellite data and complex processing (Dubovyk 2017) and is still not at sufficient resolution to detect small scale changes, but may be useful for broader landscape level changes (e.g., Trends.Earth 2018). While the CSRScan does not detect invasive species or other changes in vegetation, our approach does provide unique value by efficiently identifying visibly degraded sites with bare

ground, sparse vegetation, or unauthorized trails over large areas and provides accurate information useful for effective prioritization and planning at a low cost.

The CSRScan maps and associated tables can be used in a number of ways to prioritize restoration according to conservation of biodiversity, supporting ecosystem services, or enhancing the integrity of protected areas, for example (CBD Secretariat and Society for Ecological Restoration 2019). The CSRScan products include spreadsheets for sorting sites according to size, type of disturbance, and access to help with prioritization and planning efforts. Paired with the USDA NRCS ESDs, the maps and associated tables provide rich information that can help managers best choose areas for restoration given limited resources, and help plan what plant species to include if choosing to seed or plant. With these resources, managers should visit sites to verify soils and identify nearby plant community composition to help guide restoration decisions. There are many resources currently available to help guide planning, implementing, and monitoring restorations once sites have been identified and prioritized (Gann et al. 2019).

Utilizing citizen scientists reduces costs and speeds the process dramatically. By having multiple volunteers working in parallel, elapsed project times could be as short as several weeks. However, it must be emphasized that citizen scientists require detailed training and support to execute their tasks correctly. In our case, we were able to have a citizen scientist lead conduct the majority of the work. However, it may not always be possible to recruit a citizen scientist willing or able to accomplish these tasks, therefore staff time required may be higher. Freely available software and resources (Google Earth and the USDA NRCS Web Soil Survey online instrument) also keep costs low. Although the CSRScan approach requires access to GIS software, such software may be available at low-cost to nonprofit organizations and others and QGIS (from the Open Source Geospatial Foundation accessed at <https://qgis.org/en/site/>) is a free alternative. Potentially the most challenging resource to obtain is high-resolution aerial photos of the area being surveyed, but the satellite imagery available on Google Earth can be used with less precision as an alternative. The availability of augmenting shape files, which are vital for the process, may also present a challenge. These shape files, showing boundaries, trails, roads, utility corridors, constructed features (equipment yards, trailheads, gates), sites where active restoration already is underway, and natural features like washes, helps volunteers focus their scans on accurately detecting new degraded sites, instead of marking known features or disturbances, and keeping the scan located within the overall boundary.

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Supporting Information

The following information may be found in the online version of this article:

Table S1. Area, type, and access of sites identified through the SCRS can approach in the Preserve.

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