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RESEARCH ARTICLE

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Comparison of Methods to Monitor the Distribution and Impacts of Unauthorized Travel Routes in a Border Park

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ABSTRACT: The distribution and abundance of human-caused disturbances vary greatly through space and time and are cause for concern among land stewards in natural areas of the southwestern borderlands between the USA and Mexico. Human migration and border protection along the international boundary create Unauthorized Trail and Road (UTR) networks across National Park Service lands and other natural areas. UTRs may cause soil erosion and compaction, damage to vegetation and cultural resources, and may stress wildlife or impede their movements. We quantify the density and severity of UTR disturbances in relation to soils, and compare the use of previously established targeted trail assessments (hereafter – targeted assessments) against randomly placed transects to detect trail densities at Coronado National Memorial in Arizona in 2011. While trail distributions were similar between methods, targeted assessments estimated a large portion of the park to have the lowest density category (0–5 trail encounters per/km^2), whereas the random transects in 2011 estimated more of the park as having the higher density categories (e.g., 15–20 encounters per km^2 category). Soil vulnerability categories that were assigned, a priori, based on published soil texture and composition did not accurately predict the impact of UTRs on soil, indicating that empirical methods may be better suited for identifying severity of compaction. While the estimates of UTR encounter frequencies were greater using the random transects than the targeted assessments for a relatively short period of time, it is difficult to determine whether this difference is dependent on greater cross-border activity, differences in technique, or from confounding environmental factors. Future surveys using standardized sampling techniques would increase accuracy.

Index terms: disturbance, international border, soil impacts, US/Mexico, unauthorized trails and roads

INTRODUCTION

Roads and trails in natural areas are well known sources of disturbance that are a serious concern for park managers and resource specialists, alike (Bratton et al. 1979; Webb and Wilshire 1980; Prose et al. 1987; Godwin 2000; Belnap et al. 2001; Webb 2002). Furthermore, increases in Unauthorized Trail and Road (UTR) networks add to disturbances penetrating deeper into formerly less accessible areas (Madsen 2007). These disturbances can even alter animal behavior and wildlife movements as a result of changes in human movements across the landscape (Miller et al. 2001; Ament et al. 2008; Flesch et al. 2010). Habitat modification in some cases can include changes in vegetation community structure and cover, soil compaction and erosion, water resource degradation, and can lead to economic losses and strife among residents and immigrants (McIntyre and Weeks 2002). Accurate estimation of the quantity of UTRs, their positions on the landscape, and their effects on soils and biota can be used to assess the effects of human activities on natural systems through time and space (Quijada-Mascareñas et al. 2013; Villarreal et al. 2014). Public lands in regions surrounding international borders are vulnerable to disturbances from illegal human traffic, contraband smuggling, and related border-security interdiction efforts (GNEB 2010). These activities create an ever-changing network of disturbance caused by UTRs across the landscape (Quijada-Mascareñas et al. 2013). UTRs are typically linear disturbances where vegetation is damaged or missing, and soil surfaces are disturbed by compaction, flocculation, or erosion and are visible to the extent that subsequent observers may follow the linear paths. These trails frequently have areas of more expansive disturbance where people rest during their travels across the landscape. Such areas have more extensive vegetation and soil disturbance and frequently discarded trash. High density trailed areas include trail networks that are extremely challenging to document due to their fluctuating use and convoluted dendritic pattern across landscapes, the large expanses of land they cover, obstruction by vegetation, the status of current detection methods, safety considerations, and the logistics associated with conducting surveys amidst interdiction activities led by law enforcement officials.

National Park Service (NPS) units along the international border in Arizona have used various methods to identify patterns of UTRs believed to be shifting over time and space in response to Border Patrol interdiction activities, border fences, and border walls designed to reduce traffic (McIntyre and Weeks 2002; Povilitis and Fallon 2006; Rutman 2006). Remote sensing techniques have been employed to estimate trail distribution in natural areas dominated by chaparral and desert vegetation (Kaiser et al. 2004; Cao et al. 2007, respectively). However, Coronado National Memorial (CORO) has higher elevation than many desert natural areas and the dense vegetative cover in woodland and forested parts of the park precluded the success of previously attempted remote sensing techniques. Thus, ground-based methods have been employed in some border parks of Arizona to overcome the challenge. For example, Organ Pipe Cactus National Monument (ORPI) used east-west transects that were surveyed parallel to the international border, assuming the majority of trails were oriented north-south. Coronado National Memorial implemented a method to inventory trails, tracing the length of each trail and its branch to gain an estimation of the impacts to the park. Similar transects were surveyed at Chiricahua National Monument (CHIR) and Fort Bowie National Historic Site (FOBO). However, differing methods, and the variable results from these previous transects, were not sufficiently rigorous to meet management needs (J. DeGayner, National Park Service, pers. comm.).

In collaboration with NPS, our first objective was to design a standardized protocol to quantify the distribution and severity of UTRs, and to compare results to previous patterns throughout CORO. While the targeted assessments were conducted with the goal to create a complete assessment of UTRs (especially in smaller parks), we hypothesized that they underrepresented density and provided a biased geographic distribution of UTRs. Therefore, we proposed that a random transect sampling strategy would encounter additional UTRs not identified in the targeted assessments. Our second objective was to predict the severity of soil disturbances from damage by UTRs by employing standardized soil engineering techniques to quantify differences in soil surfaces between relatively undisturbed natural surfaces in national parks and UTR surfaces that dissect these areas. We used published descriptions of mapped soil parameters (Soil Survey Staff 2009) and a Soil Survey of Coronado National Memorial (Denny and Peacock 2000).

METHODS

Coronado National Memorial covers 19.23 km^2, with elevations ranging from ~1480 to 2230 m. It is located in Cochise County, Arizona, with all 5.63 km (3.5 mi) of its southern boundary along the United States–Mexico border (Figure 1). Long-term (1960 to 2005) average annual temperatures ranged from a maximum in July (32.3 ˚C), to a minimum in January (0.3 ˚C, WRCC 2015). Long-term average annual precipitation is 552.9 mm. On average, some precipitation occurs every month of the year and is dominated by summer storms that peak in July/August (41% of mean annual precipitation), with occasional continental winter storms that peak in December/January (18% of mean annual precipitation). Freezing temperatures may occur for brief periods, with the potential for snowfall (<60 mm per month) from November to March (WRCC 2015).

Geology at CORO is complicated by volcanic activities related to the Montezuma caldera, which caused seismic activity and folding that reorganized the juxtaposition of geological strata such that in some cases geologically younger materials may occur on top of older materials (Denny and Peacock 2000). Parent materials are derived from Jurassic granites, volcanics, and sedimentary rock making up the major mountain outcrops, with younger early Pleistocene to latest Pliocene surficial deposits in the lower elevations of the park and along the international boundary (Arizona Geological Survey 2000). The head of Montezuma Canyon is in the northwest of the park trending southeast to the lowest point in the park. Montezuma Valley is flanked by a large south-facing mountain on the north that runs to the top of an east-west running ridge—the highest point in the park. To the south, Smuggler's Ridge flanks Montezuma Valley, with the international border south of that ridge. There were 20 soil types identified in the park and most were loamy with some fine loams and clays (Table 1, Denny and Peacock 2000; Soil Conservation Staff 2009). Soils on extremely steep hillslopes are thin (Denny and Peacock 2000) and prone to slides and debris flows over much of the park (Youberg et al. 2006).

Desert grassland vegetation, dominated by the invasive Lehmann lovegrass (*Eragrostis lehmanniana* Nees), and interspersed by visually prominent Palmer's agave (*Agave palmeri* Engelm.), various oaks *(Quercus* spp.), and mesquite trees (*Prosopis* spp.) are found at lower elevations in the park. Middle elevations make up the greatest portion of the CORO landscape and are dominated by oak woodlands interspersed by steep grassy slopes and rocky outcrops. High elevation areas are characterized as "sky islands," and are occupied by interior chaparral and stands of mixed conifers.

The shared international border between CORO and Mexico was easily crossed on foot or by vehicle until 2009 (i.e., prior to any surveys described in this paper). After that time, a border fence (~6-m tall) was constructed that partially bounded the park by extending from lands east of the park along 2.5 km of the park border, before ending abruptly as the terrain rises at the foot of Yaqui Ridge. Subsequently, the border could not easily be crossed where the fence existed, and as a result, undocumented traffic flow was influenced (but not stopped). To further complicate backcountry sampling efforts, the park is subject to intermittent (i.e., days or weeks) or long-term (i.e., foreseeable future) partial closures as a safeguard against known or perceived threats from illegal border activity and interdiction efforts. Park law enforcement staff and the Department of Homeland Security collaborate on border safety issues throughout the park. The extremely rough terrain primarily restricts interdiction efforts in some of the mountainous areas to vehicular traffic on established roads, aerial surveillance, foot traffic on trails, or instrumented surveillance.

UTR Sampling Methods

In regard to targeted assessments and random trail sampling, the term "trail" refers minimally to surface soil and vegetation compaction indicating use by a motor vehicle or enough foot traffic that a linear disturbance was detectable as a tread on the soil surface. We estimated the density and geographic distribution of UTRs in

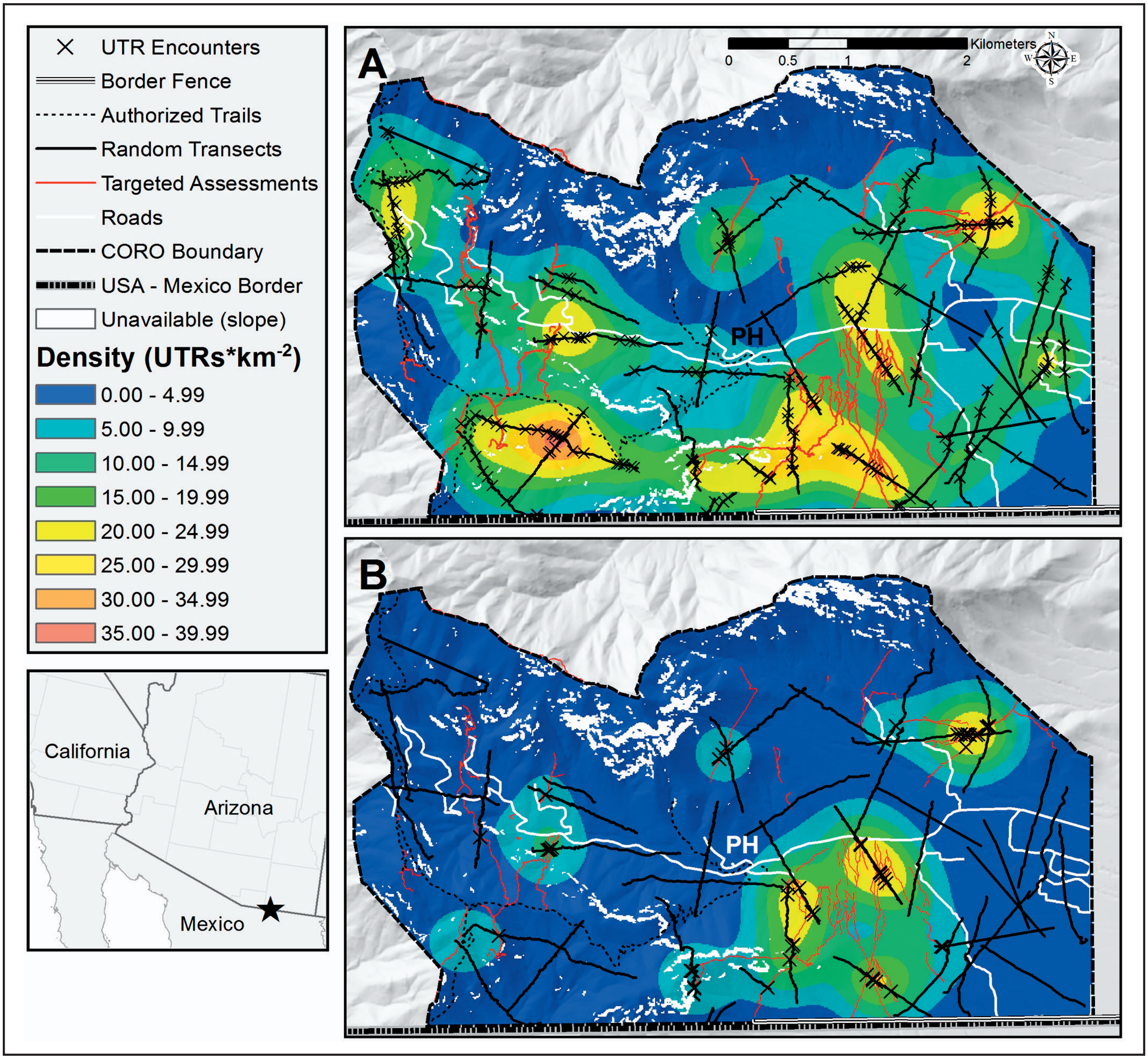

Figure 1. Study area and random transects. Forty-two random transects surveyed at Coronado National Memorial, Cochise Co., Arizona, in 2011. Areas with slope greater than 40° were removed from analyses and are shown as white polygons. (A) UTR intersections (black X) encountered along the 42 random transects (black lines) in 2011. Paved roads (solid white) and authorized trails (dashed black) are shown for reference. (B) UTR intersections (black X) that would have been encountered if the targeted assessments actually captured 100% coverage of UTR intersections. The white lettering, PH, represents park headquarters.

CORO using a random transect sampling method (described below) during 10 working days in January and February 2011. We compared our estimates of density and distribution of disturbances to data collected on UTRs by the NPS using a similar or shorter amount of cumulative time investment during November through January of 2009. NPS – CORO provided unpublished UTR data, referred to as "targeted assessments" hereafter. For the targeted assessments, NPS staff and interns travelled along known roads and routes to identify intersecting trails. Identified trails and their secondary branches were mapped with a Global Positioning System (GPS) by traveling along each to its apparent termination or until it was no longer possible to follow within the boundaries of the park. Along with information from law enforcement staff, NPS staff used these targeted assessments to locate as many UTRs as possible, with a goal of 100% coverage throughout the park. However,

Table 1. Named soil types, vulnerability classifications assigned by expert opinion (Soil Index), and soil type descriptors used to assign vulnerability from National Resource Conservation Service, STATSGO data (Soil Survey Staff 2009).

Soil Name	Area (km^2)	Soil Index	Bulk Density	Org. Matter (%)	Clay (%)	Sand (%)	Silt (%)	Surface Texture
Hogris-telephone-Rock outcrop association	0.187	Low	1.37	1.5	16.8	58.4	24.7	very cobbly sandy loam
Faraway-Tortugas-rock outcrop association	1.612	Low	1.39	1.79	14.2	57.5	28.3	very cobbly fine sandy loam
Rock outcrop-Lithic Haplustolls association	2.662	Low	0	0	0	0	0	not applicable
Hogris-telephone association	0.073	Med	1.37	1.5	16.7	59	24.3	very cobbly sandy loam
Barkerville-Gaddes association	0.224	Low	1.43	1.25	7.5	68.8	23.7	cobbly sandy loam
Barkerville-Gaddes association	3.297	Low	1.43	1.25	7.5	68.8	23.7	cobbly sandy loam
Sonoita gravelly sandy loam	1.968	High	1.43	0.75	10	66.9	23.1	gravelly sandy loam
Rock outcrop	0.366	Low	0	0	0	0	0	not applicable
White house gravelly loam	0.936	High	1.35	1.5	25	38.5	36.5	gravelly loam
Martinez gravelly loam	0.235	High	1.33	1.5	21	41.6	37.4	gravelly loam
Rock outcrop-lithic Haplustolls association	3.298	Low	0	0	0	0	0	not applicable
Barkerville-Gaddes complex	0.256	Low	1.43	1.25	7.7	68.7	23.6	cobbly sandy loam
Hogris-telephone association	1.229	Med	1.37	1.5	16.7	59	24.3	very cobbly sandy loam
White house gravelly loam	1.413	High	1.35	1.5	25	38.5	36.5	gravelly loam
Torrifluvents and haplustolls	0.12	Med	0	0	0	0	0	not applicable
Grabe-comoro complex	0.228	High	1.42	1	11	66	23	sandy loam
White house gravelly loam	0.52	High	1.35	1.5	25	38.5	36.5	gravelly loam
Barkerville-Gaddes association	0.586	Low	1.43	1.25	7.5	68.8	23.7	cobbly sandy loam
Faraway-rock outcrop complex	0.362	Low	1.43	2	10	68.5	21.5	very cobbly fine sandy loam
White house gravelly loam	0.095	High	1.35	1.5	25	38.5	36.5	gravelly loam

areas in the southwest region of the park were restricted from access during many of the targeted assessments. These areas were also partially restricted during the random transects due to safety concerns regarding illegal activities in the area.

In contrast to the targeted assessments, the random transects were designed to provide consistent sampling intensity throughout the park. We placed linear transects randomly throughout the park and walked the transects in random directions. Transects were limited to areas with less than 40° slope for safety considerations for field crews. As with the targeted assessments, law enforcement closures due to interdiction activities made some areas of the park unavailable for sampling on certain dates. We sampled 42 transects in January and February 2011, each approximately 1-km long (Figure 1). We originally identified 100 random transects; however, due to time and resource constraints, the number was truncated to 42. In retrospect, this number provided good coverage while avoiding excessive sampling redundancy. Field teams traversed each transect on foot and recorded the location of any UTRs encountered.

We estimated the density and distribution of UTRs in CORO by calculating a kernel density surface to provide a mapped interpolation of the UTR point density throughout the park from the intercepts with UTRs along the random transects. The density surface was expressed in terms of the number of UTRs per km^2. It was created with a Gaussian kernel density function as defined by Okabe et al. (2009) in GRASS 6.4 (Grass Development Team 2008) with a standard deviation of 250 m, represented as one quarter length of each transect. We maintained the spatial resolution for all raster calculations at 10 m, which was comparable to the spatial resolution of all GPS units used during field surveys. Areas that were unavailable for sampling due to extreme slope were excluded from analyses. In addition to UTR density, we report the transect encounter rate (UTR encounters per kilometer walked) and standard error to give an estimate of the distance of transect that needed to be surveyed before encountering a UTR within CORO.

Comparison of Random Transects to Targeted Assessments

To compare the random transect sampling method to the targeted assessments, we estimated the density of UTRs that would have been found on our random transects if the targeted assessments had provided 100% coverage and represented the true distribution of UTRs in the park (generally assumed to be nearly 100% by the NPS at the time). We subsampled the GPS tracks from the targeted assessments by intersecting them with the random transects in a Geographic Information System and identified which UTRs included in the targeted assessments would have been encountered by the random transects if they were still visible to field crews in 2011. We maintained error tolerances (also known as fuzzy tolerance) at 10 m to approximate average GPS error, and to reduce the number of false positive intersects due to the jagged shape of the GPS tracks for targeted assessments. We then estimated the density and geographic distribution of these UTR encounters using the same methods for the random transects. Density is reported as UTR encounters per km^2 and is given as the average across the entire park for both the random transects and targeted assessments. Separately, we calculated the difference in density between the two methods by subtracting the density surface of the targeted assessments from the density surface of the random transects, and highlighted areas where they differed or were congruent. We hypothesized that the targeted assessments would underrepresent high UTR density because field personnel spent the majority of their sampling effort tracing individual UTRs rather than enumerating additional (and possibly nearby) UTRs, and because the targeted assessments were limited to UTRs that crossed existing roads and trails, which did not cover much of the park.

Trail Cross-sectional Topography

We analyzed the cross section of trails by (1) assessing the trail condition (i.e., down-cutting, compaction and erosion), and (2) analyzing relationships between soil type and vulnerability to compaction and erosion. Trail condition was assessed using measures of cross-sectional trail topography. We quantified the relative elevations for berms and treads of trails in relation to the surrounding landscape by measuring elevations of primary inflection points in trail cross sections (Figure 2) and by adapting "cut and fill" road-building analyses (Harbin 2001). A reference line across each trail was established by extending a string between stakes that we placed 1 m outside the berm on either side of the trail (Figure 2 points A and G). Vertical measurements were taken from the string to the ground at predetermined points along the string such that depressions (e.g., due to loss or compaction of soil) were larger values and ridges (such as the berm of the trail) were relatively smaller values. Trail cross sections were assessed by measuring the vertical distance between the ground and reference lines.

The relationship between each point and the ground was adjusted using the endpoints of the cross sections to correct for the slope of the terrain. A nonlinear curve was fit to the cross-sectional points using a penalized spline analysis (Meyer 2008) to depict the theoretical ground level, which effectively interpolates a simulated surface between all points. The cross-sectional area (for the area above and below the statistically derived ground level) was calculated as the area under the curve, and the net changes (interpreted as loss or gain of material) were calculated as the area (cm^2) above the interpolated ground surface (soil deposition or dilation) minus the area below the interpolated ground surface (compaction or erosion). These values represent the net impact where each trail cross section was measured. Whenever possible, three replicates were taken at each trail encountered on the random transect (i.e., one at the actual trail intercept, and one at 10 m in either direction along the trail), and the values were averaged.

Relationship between Trail Condition and Hypothesized Soil Vulnerability

Soil vulnerability categories (low, medium, and high) were assigned, a priori, by USGS staff using expert opinion (R.H. Webb, USGS Arizona Water Science Center), and were based on the physical relationships between parent material, bulk density, and soil texture for soils described in the

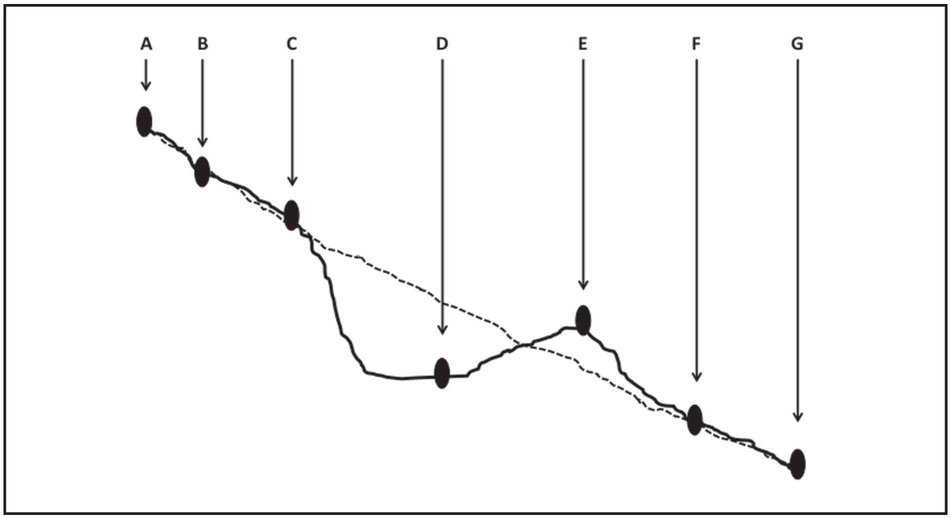

Figure 2. Cross-sectional topography of a representative single-track trail. Seven measurement points (A through G) were measured in order to complete the analysis of the cross section of this trail in relation to others. The dashed line represents the hypothetical hillslope of the undisturbed area, and the solid line between points C and F represents the slope that is impacted by a trail. In this depiction A, B, F, and G represent the background hillslope, C and E represent the trail berm, and D represents the tread (i.e., the low spot on the trail).

CORO soils polygon map (Table 1, Soil Index; Denny and Peacock 2000; Soil Survey Staff 2009). These characteristics were used to predict vulnerability to soil compaction or flocculation, both of which can lead to soil erosion. The net loss or gain of materials from the quantification of trail cross sections (described above) was compared to the vulnerability class assigned to each soil type. Net impacts were compared among soil types using an ANOVA.

RESULTS

Most of the UTRs encountered during random transects and targeted assessments appeared to be caused by foot traffic in Coronado National Memorial. Only two 2-track vehicular trails were encountered, and they occurred on the relatively flat areas directly along the international border in the southeastern extent of the park.

Random Transects, Targeted Assessments, and Their Comparisons

We encountered 213 UTRs along the 48.3 km of random transects, resulting in an average transect encounter rate of 4.74 UTRs per km of transect (SE 0.58). On one transect no UTRs were encountered, while 75% encountered five or more UTRs, with encounter rates ranging from 0 to 18.24 UTRs per 1 km of transect.

The kernel density surface resulted in a geographic average of 10.3 and a maximum of 36.3 UTR encounters per km^2. Areas with the highest (>35) UTR density were limited to the southwestern sector of the park (Figure 1A), though areas with densities above 30 UTRs per km^2 were found throughout the southern and northwestern regions as well (Figure 1A). In particular, we identified three areas where trail densities were elevated above the lowest detection category (i.e., 0–5 encounters per km^2, Figure 1A). Bob Thompson Peak in the northeast of the park is a traditional travel route and is currently a heavily used route for trans-border human traffic (M. Stoffolono, NPS law enforcement, pers. comm.). The targeted assessment data illustrate a similar pattern (see below). A single large area in the southwest of the park had trail densities at the highest classes, and a third area in the south-central portion of the park had slightly elevated area trail densities (Figure 1A).

We do not report encounter rates for the targeted assessments because these encounters were subsampled to an equivalent sampling effort of the random transects, and not actually resampled by our field crews. Instead, we used the targeted assessment encounters to derive a kernel density surface (Figure 1B). We found 47 simulated encounters with UTRs, which translated to a geographic average of 3.9 encounters per km^2 and a maximum of 27.2 encounters per km^2.

Comparing targeted assessment data from 2009 with random transects in 2011, we found a great disparity in the detection of trails between the two methods (i.e., 462% fewer UTRs were estimated from targeted assessments compared to random transects). The average park-wide density of UTR encounters was 3.9 per km^2 using targeted assessments versus 10.3 per km^2 using random transects—a 164% increase for random transects. The estimation of trail encounters from the targeted assessment method suggests that most of the park has low numbers of trails (Figure 1B), but the random transects estimated greater numbers of trail encounters in all of the higher encounter rate classifications, indicating overall greater numbers of trails in the park (Table 2).

Comparing the two methods, there were large areas of similar density throughout the park, and the greatest differences (random transects minus targeted assessments) occurred in relatively smaller areas in the eastern one-half of the park (Figure 3). Targeted assessments identified a concentration of UTR encounters in the southeastern portion of the park, primarily in slopes below 15° (Figure 1B). This concentration of UTR detections surrounds park headquarters and is also encompassed by a high density area of UTR encounters detected by random transects. The second greatest concentration of UTR activity using targeted assessments occurs in the northeast corner of the park, and is consistent with a high concentration area identified using the random transects (Figure 1A). In addition to these sites, six other areas with trail encounters above the lowest detection category were identified by targeted assessment; however, in all cases the estimated encounter rates were higher for random transects (Figures 1A and B).

Table 2. Comparison of the estimated encounters / km^2 for random transects versus targeted assessments at Coronado National Memorial, Cochise County, Arizona, in 2011.

Encounters / km^2	Class	Random Transects (km^2)	Targeted Assessments (km^2)
0-4.99	1	5.176	13.855
5-9.99	2	4.926	2.557
10-14.99	3	4.056	1.193
15-19.99	4	2.398	0.789
20-24.99	5	1.575	0.395
25-29.99	6	0.597	0.072
30-34.99	7	0.109	0
35-39.99	8	0.023	0

Relationship between Trail Condition and Soil Vulnerability

Field teams collected trail cross sections at 204 trail intersections along 42 transects. Based on the a priori assignment of vulnerability classes, we identified 57 unique trails on high vulnerability soils, 25 on medium vulnerability soils, and 122 on low vulnerability soils. The soil vulnerability categories that we assigned by expert opinion did not have a significant relationship with soil cross section displacement ($F_{2\ 201}$ = 0.74, P = 0.48). Thus our hypothesis regarding soil vulnerability categories based on expert opinions about soil texture and composition from soil survey data at this site was rejected. However, the measurements of soil displacement did provide useful information with regard to trail impacts throughout the park. Highly disturbed sites (as defined by greatest measureable soil displacement) were not actually as common as Low or Medium disturbed sites at CORO (Figure 4). Severity of trail impacts as measured by soil displacement tended to be higher in the northern portions of the park where the frequency of UTRs was lower than in the southern sections of the park.

DISCUSSION

We identified more UTRs by surveying with random transects than were identified using the targeted assessments. Low trail density estimates from the targeted assessments could be related to temporal variation in the amount of trailing visible due to changes in activity patterns of people using the area. Human activity in the area may vary due to season (e.g., fewer

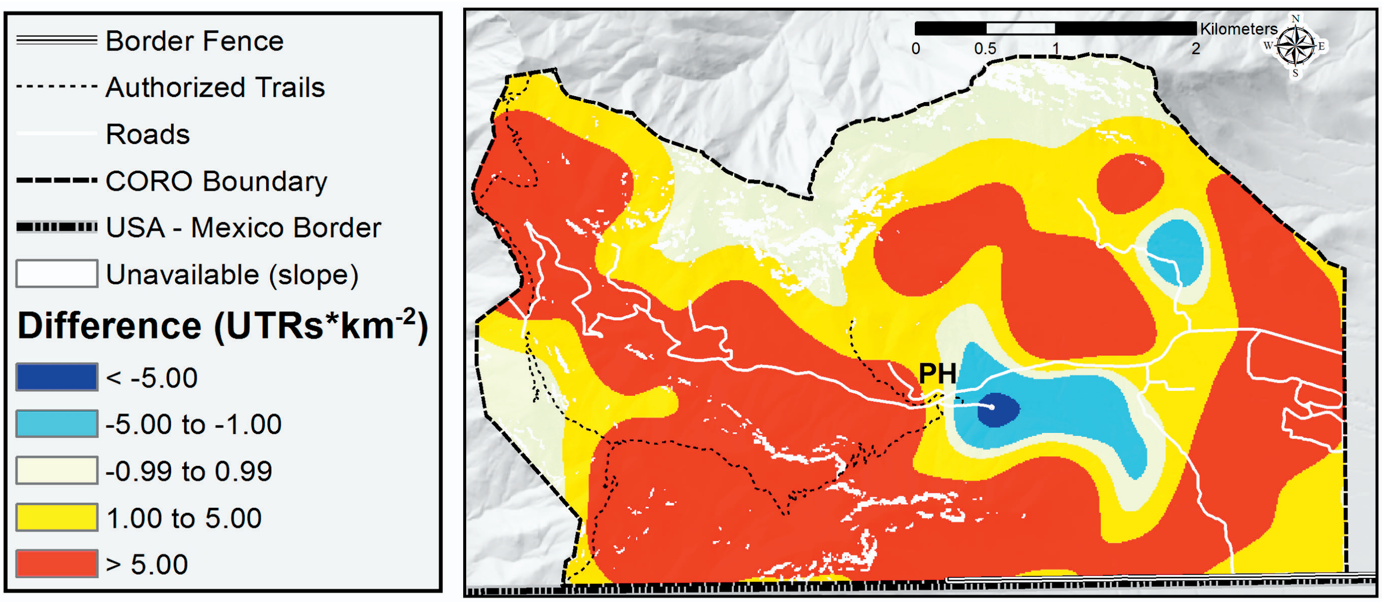

Figure 3. Comparison showing the difference in estimated UTRs per km2 between random transects (2011) and targeted assessments (2010) at Coronado National Memorial, Cochise Co., Arizona.

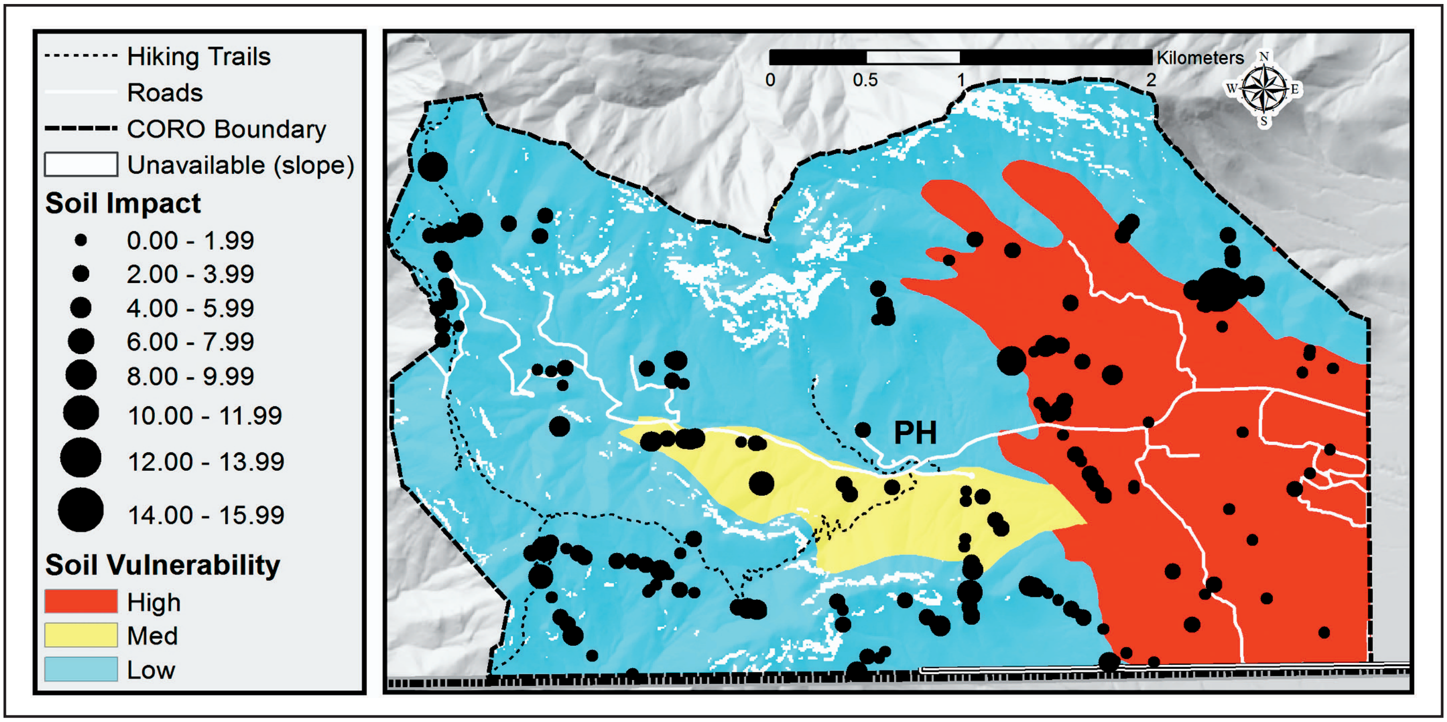

Figure 4. Topographic relief map of Coronado National Memorial, Cochise County, Arizona, indicating relative soil vulnerability. Red, yellow, and blue shading depict High, Moderate, and Low soil vulnerability, respectively. The size of the circles illustrates the relative amount of disturbance found on UTRs associated with transects (e.g., largest circles depict greatest impact to soils). The black lettering, PH, represent Park Headquarters.

people travel during the hottest season), in response to demand for contraband, or in response to known or perceived changes in interdiction activities by law enforcement (M. Stoffolono, NPS law enforcement, pers. comm.). Alternatively, trails may be obscured seasonally by increased summer vegetation or weathering of trails due to major storm events, or by variability in personnel performance (e.g., motivation, thoroughness) while collecting data. The targeted assessments required field personnel to follow each UTR to its terminus, which may have been misidentified (e.g., the observer determined that the trail ended when in fact it did not). While conducting random transects, we noted that trails sometimes occurred in a braided pattern. Because of this, it was possible to lose trails intermittently (i.e., if one continued along the trail trajectory, the trail was again discernible a little farther along). Intermittence of UTR visibility may be caused by substrate patches or changes in the behavior of the people making trails that do not lend to tracks or treads being visible. Presumably when the trail resumes, it is the same trail, though this is likely not always the case in heavily trailed areas where multiple trails may intertwine, thus causing further confusion. Alternatively, the removal of vegetation over large areas due to fires may reveal trails that were previously obscured (e.g., the Monument Fire disturbed nearly 29,000 acres in and around the park in June of 2011). We speculate that most or all of these factors played some role in the discrepancies between the targeted assessments and random transects. However, we concluded that differences between the two methods were the largest factor in discrepancies of UTR distributions. Only trails intercepting existing roads and routes (and their secondary branches) were identified by the targeted assessment teams, thus truncating the potential search area for trails compared to random transects that sampled the entire park (excluding topographically dangerous areas). Also, the area surrounding the NPS headquarters was the most extensively surveyed using the targeted assessments, with less attention paid to distal areas in the park to the west, and especially in the northern extent of the park (Figure 1B), which had slopes typically exceeding 15%. Further, most of the trails encountered on the random transects had well-established treads that likely reflected a great deal of activity, possibly accumulated over years of activity under a variety of conditions (Webb et al. 2013). Thus, we conclude that the additional UTRs encountered on the random transects were unlikely to have been established in the short time between the targeted assessments and the random transects, which lends more credibility to the differences in UTR encounter rates between the two methods.

The two survey techniques highlight some similarities in the disturbance patterns at CORO. The earlier targeted assessments indicated that the greatest amount of disturbance occurred in the southeast portion of the park, followed by another disturbed area in the northeast corner, and a third mild disturbance area in the west-central portion of the park (Figure 1B). The random transects also detected disturbances in these areas, but highlighted many more areas with significant levels of impact, and indicated greater numbers of trails throughout the park, which likely impact the park substantially. A previously undescribed disturbance area was also identified in the southwest portion of the park where few UTRs were previously documented. It is possible that the relatively greater trail density resulted from recent changes in traffic patterns due to the introduction of the border fence in the southeast corner of the park in 2009. Furthermore, at the time when the random surveys occurred, law enforcement activities were also focused in the southwest, indicating that law enforcement personnel in the park were probably aware of trail use, while the earlier natural resources teams either did not, or were not allowed to survey the area due to intermittent closures resulting from safety concerns.

Soil Vulnerability and Disturbance

The US Natural Resource Conservation Service, Soil Survey Geographic database soils datasets (Soil Survey Staff 2009) do not provide soil vulnerability characterization, but we hypothesized that data found therein might be used to predict soil vulnerability. For example, areas with high bulk density were assumed to be compacted naturally, and sandy loamy soils are known to be more vulnerable to compaction than rocky, gravelly soils. These characteristics were used to predict vulnerability to soil compaction or flocculation, both of which can lead to soil erosion. However, we rejected our hypothesis because soil vulnerabilities did not correlate with compaction levels as measured by our trail profiles, and thus do not adequately explain the true vulnerability to disturbance in the field at this site (Webb et al. 2014). This may be due to the limited resolution of the analyses for the existing soil surveys. While gravelly soils such as those found on the uplands would generally be less susceptible to compaction than loamy soils in the lowland areas, it is possible that the extreme slope of the uplands contributed more to soil losses than soil compaction. The rejection of this hypothesis precludes using a priori assignment of soil vulnerabilities with currently available data and, thus, the method did not become a useful tool. More detailed soil characteristics will be required if further efforts are made to predict the relative levels of vulnerability on these soils.

Application and Dissemination of Technique

In this study, 42 transects were used to survey the park for the location and severity of damage to soils by UTRs. The data collected here were shared with law enforcement and resources staff at CORO and received positive feedback on the usefulness of the information. In particular, these "ground-based" surveys provide new information about portions of the park where aerial surveillance and trail detection using remote sensing is currently precluded by cover from trees. Furthermore, this method provides a baseline for future comparisons. These methods may be useful in a number of other natural area locations. The demand for higher resolution, quantitative, and spatially accurate data has increased in response to increased border activity. This project demonstrated a technique that is (1) easily taught to new and seasonal personnel, (2) results in park-wide surveys for trails, (3) is capable of documenting the level of trail disturbance as well as trail density, and (4) can be implemented with minimal field effort (e.g., team of 6 in 10 days of field work) such that it is feasible to conduct on an annual basis if change detection is a priority management objective.

CONCLUSIONS

We designed and implemented a random sampling technique and estimated the density and distribution of UTRs in comparison to a targeted assessment technique. The random transects we used provided substantially greater estimates for the density of UTRs, and greater coverage of the park area by surveys. We found the current density of trails to be approximately 10.3 per km^2. Furthermore, random transects identified that a great deal of the park is experiencing a higher density of use than was detected using the targeted assessments. Based on data collected here, we estimate that about fifty 1-km random transects are appropriate for surveying a park of this size. We did not find a significant relationship between the a priori estimates of soil vulnerability when compared to the empirical field measurements; thus, assigning soil vulnerability to disturbance was not useful for soils in this area given the resolution of current soil surveys. However, adapting the engineering techniques to estimate soil losses to compaction and erosion were useful at CORO. These data represent a baseline against which future measurements could be compared. One useful form of validation would be to share data with law enforcement to find out if estimated fluctuations in the use of the CORO backcountry are similar to observations of cross border traffic.

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