

Bodily Inertia and the Weaponization of the Sonoran Desert in US Boundary Enforcement: A GIS Modeling of Migration Routes through Arizona's Altar Valley

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Executive Summary

This article conducts geographic information system (GIS) modeling of unauthorized migration routes in the Sonoran Desert in southern Arizona and finds an increase in the ruggedness of terrain crossed by pedestrian travelers throughout time. The modeling of ruggedness incorporates multiple variables that include slope, vegetation, “jaggedness,” and ground temperature, and provides an alternative to Euclidian distance as a way of measuring and conceptualizing borderlands space.

The data that informs our analysis is derived from comprehensive activity logs maintained by the humanitarian organization No More Deaths from 2012 to 2015, including 4,847 unique entries documenting the use of 27,439 gallons of clean drinking water at 512 distinct geotagged cache sites located along known pedestrian migration routes. The shift in migration routes toward more difficult terrain within this one high-traffic corridor reveals the ongoing impacts of the US Border Patrol's strategy of “Prevention Through Deterrence.” In short, the pressures of enforcement on migration routes combine with everyday interference with humanitarian relief (No More Deaths and Coalición de Derechos Humanos 2018) to maximize the physiological harm experienced by unauthorized migrants. Among other outcomes, this explains both the persistence of mortality of unauthorized migrants and an increase in the rate of mortality over time (Martínez et al. 2014). The article concludes with several policy recommendations for US Customs and Border Protection that include making interference and vandalism of humanitarian aid a fireable offense; the formation of a border-wide agency tasked with search-and-rescue and emergency medical response, whose mission and operations are restrained by a clear firewall between itself and those of law enforcement; and ending Prevention Through Deterrence as a nationwide strategy.

Keywords

US–Mexico border, prevention through deterrence, mortality, geographic information systems (GIS)

Introduction

Since 2000, 3,199 human remains of unauthorized migrants have been recovered from the Sonoran Desert of southern Arizona (Coalición de Derechos Humanos 2018). These recovered remains provide only one indicator of the scope of death and suffering affecting unauthorized migrants and their loved ones — something that also includes thousands of individuals whose whereabouts or remains are never encountered (and who therefore remain disappeared) (ibid.). Just as significantly, the number of human remains recovered in southern Arizona has remained consistently high despite a significant decline during the past decade in the number of apprehensions (a figure frequently used as a proxy for unauthorized migration) in the Border Patrol's Tucson Sector.

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This condition has led scholars and commentators alike to observe an increase in the *ratio* of deaths to migration, even as unauthorized border crossing fluctuates (Martínez et al. 2014; Reineke and Martínez 2014; International Organization for Migration 2018).

In 2012, the southern Arizona humanitarian organization No More Deaths began systematically tracking the use and vandalism of cached drinking water it supplies at 512 sites across an 800-square-mile area of southern Arizona's Altar Valley, a high-traffic migration corridor bisected by the US–Mexico border (Ferguson, Price, and Parks 2010; Regan 2010; Boyce 2016; Chambers et al. 2019). On an almost daily basis, volunteers with No More Deaths travel this migration corridor to resupply caches of 5–20 gallons of clean drinking water, physically hauling this water by truck and by foot. Each cache site is tracked using a Global Positioning System (GPS) coordinate to make navigation of the remote desert borderlands and the location of dispersed and frequently hidden cache sites easier for new volunteers.

In 2015, the authors began working with No More Deaths to digitize and conduct spatial and statistical analysis on the data entered into these desert aid logs, with the express aim of seeing what this archive can reveal about everyday activity related to boundary enforcement and migration, as well as the efficacy of the organization's activities throughout time. In total, No More Deaths' desert aid archive contains 4,847 unique entries from March 2012 to December 2015, logging the date when an individual cache site was visited, the number of new water gallons deposited during this visit, the number of water gallons encountered intact and unused from previous resupply visits, the conditions of any empty water bottles left behind (including telltale signs of human vandalism, as well as occasional animal damage), and any subjectively unusual conditions or noteworthy events that were observed at the site or during the visit.

Combined, this archive provides remarkable and uncommon insight into subtle changes in migration routes and patterns within the Altar Valley desert corridor, as well as those quotidian forms of harassment and vandalism of water supplies that we believe are intended to amplify and maximize hardship for unauthorized border crossers. Indeed, scholars have long argued that the US Border Patrol's enforcement strategy of "Prevention Through Deterrence" (PTD), first launched in 1994, is premised on instrumentalizing the difficult climate and terrain of the US–Mexico border by pushing migration routes away from traditional urban crossing areas and into increasingly rugged and remote desert areas (Andreas 2001; Cornelius 2001; Rubio-Goldsmith et al. 2006; Nevins 2008; Martínez et al. 2014; De León 2015; Slack et al. 2016). The Border Patrol's own policy documents make this case. Observing that migrants "crossing through remote, uninhabited expanses of land and sea along the border can find themselves in mortal danger," the Immigration and Naturalization Service (INS — at the time, the Border Patrol's parent agency) argued that by channeling migration routes into "harsh terrain less suitable for crossing and more suitable for enforcement," the Border Patrol would eventually obtain a "tactical advantage" over would-be border crossers (INS 1994, 7). Then–INS Commissioner Doris Meissner later reflected, "We did believe that geography would be an ally for us. It was our sense that the number of people crossing through the Arizona desert would go down to a trickle once people realized what [it's] like" (quoted in Cornelius 2005).

In this article, we conduct geospatial modeling and statistical analysis of No More Deaths' desert aid archive. This involves measuring changes in the distribution of water use throughout time across the 62 cache sites consistently visited during all four calendar years included in the dataset, and then reading this measurement against a model of ruggedness that incorporates multiple variables including slope, vegetation, "jaggedness," and ground temperature while controlling for Euclidian distance. Adjusting for seasonal variation and the overall volume of water use, we find a statistically meaningful increase in the cumulative ruggedness score of migration routes associated with cache sites during the four calendar years included in No More Deaths' desert aid logs. These findings reveal a steady pressure toward more rugged and difficult crossing routes throughout time, an outcome that provides important context for the vandalism and harassment that target migrants and humanitarian aid workers alike (see No More Deaths and Coalición de Derechos Humanos 2018).

In what follows, we first provide greater detail on the context of our study and of the authors' collaboration with No More Deaths. Next, we discuss our research methodology, including the contours of the geographic information system (GIS) modeling through which we conduct our analysis. We then present our findings, and discuss and contextualize these, before turning to some of the limitations of our study and directions for future research. We conclude by considering some of the policy implications of our findings, as well as their implications for studies of mobility, border policing, and state violence, including in contexts when states are instrumentalizing environmental features and conditions for the purposes of boundary enforcement.

Context: Prevention Through Deterrence and the Geography of Humanitarian Intervention in Southern Arizona

As is well known, the contemporary era of US boundary enforcement can be traced to 1994, when the then-INS launched its first-ever nationwide enforcement strategy (see Kerwin 2001). The INS and Border Patrol's nationwide strategy aimed to push unauthorized migration away from traditional urban crossing areas like El Paso and San Diego and into more remote rural areas. At the time, it was believed that the difficult climate and terrain in these remote rural areas would isolate unauthorized border crossers, and that the level of hardship encountered would eventually serve as a deterrent, convincing would-be migrants to abandon the effort. In the Border Patrol's own internal documents, this strategy was described as "Prevention Through Deterrence" (PTD).

Even in the mid-1990s, it was anticipated that PTD would have deadly outcomes (INS 1994; GAO 1997; Cornelius 2001, 2005; Rubio-Goldsmith et al. 2006). By the turn of the century, as migration routes shifted away from Texas and California, the number of human remains of unauthorized border crossers recovered from the southern Arizona desert began to skyrocket. Between 1990 and 1999, this number averaged 12 per year (Reineke and Martínez 2014). In 2000, it grew to 136. By 2005, the number peaked at 282, before declining to 205 the following year. Although there has been some fluctuation, the number of recovered human remains has stayed between 120 and 250 every year since 2007 (Coalición de Derechos Humanos 2018). The cause of death is primarily (although by no means exclusively) exposure to the harsh desert climate and mountainous terrain where the vast majority of unauthorized crossings occur (Martínez et al. 2013). Meanwhile, the number of recovered human remains is certainly an undercount of the total number of fatalities. In 2015 alone, southern Arizona's Coalición de Derechos Humanos counted more than 1,200 missing persons cases, involving families who contacted the organization seeking help to locate a loved one. Figures like these have led human rights groups to talk about a "crisis of disappearance" along the US–Mexico border (No More Deaths and Coalición de Derechos Humanos 2018).

Starting in the early 2000s, a bevy of volunteer humanitarian organizations began to mobilize in southern Arizona to respond to the conditions described above. No More Deaths was founded in 2004 with the express aim of amplifying existing grassroots initiatives by creating a structure whereby volunteers from across the United States and beyond could come to southern Arizona for a period of anywhere from one week to several months. In June 2004, the organization launched a 24-hour desert base camp in the Altar Valley approximately 12 miles north of the Mexican boundary. The camp includes a medical clinic and rustic accommodation for up to 24 short-term volunteers. Each day, volunteers leave on multiple vehicles and foot "patrols" along remote desert roads and known migrant trails in the surrounding area.

At the time, the reasons for the organization's concentration in the Altar Valley were twofold. First, by the early 2000s, the Altar Valley had become one of the most significant corridors for migration in the United States (Ferguson, Price, and Parks 2010; Regan 2010; Boyce 2016; Chambers et al. 2019). It was also a particularly deadly corridor, given its rugged topography, lack of infrastructure (there are only two paved roads in the entire 900-square-mile area of the valley that falls on the US side of the border), and extreme temperatures (regularly lower than 32 °F in the winter months and higher than 104 °F in the summertime). Second, with a checkerboard of jurisdictions including Arizona State Trust land, the Coronado National Forest, and the Buenos Aires National Wildlife Refuge, the Altar Valley mostly comprises public lands that are accessible to grassroots civilian organizations, in contrast, for example, to the sovereign Tohono O'odham nation whose lands form the valley's western boundary, or the Barry Goldwater US Air Force Bombing Range transected by the infamous "Devil's Highway."

At first, No More Deaths' entry into the Altar Valley was ad hoc and exploratory. Volunteers would encounter a trail, or a person in need, and then repeatedly go back to the same location and share this via word of mouth. In 2006, a retired professor of science from the University of Arizona intervened in the group's practices and introduced the use of handheld GPS units to begin systematically mapping trails and trail networks, with the aim of finding more strategic areas to cache water. In the process, the GPS data provided a more robust understanding of how the spider web of migration routes that proliferate through this area intersect and form broader patterns of pedestrian traffic. As No More Deaths grew and evolved, so too did the sophistication of its data collection and record keeping. By 2011, No More Deaths (together with its sister organization, the Samaritan Patrols) had mapped more than 2,000 miles of migrant trails crisscrossing the Altar Valley and the Tumacacori Mountains on the valley's eastern edge. In 2012, the organization began to systematically track information about each site where water was cached (alongside other supplies like blankets and unopened cans of food) and every time the site was visited — what we refer to here as the organization's "desert aid logs."

Initially, the purpose of No More Deaths' desert aid logs was to pass along information about water use and water supply from one week's volunteers to the next week's, as well as to document the persistence of vandalism targeting the one-gallon jugs of clean drinking water that volunteers continuously haul to cache sites. Telltale signs like clean linear cuts at the bottom of a jug (see Figure 1) distinguish human-caused vandalism from damage caused by animals (like ravens, deer, and cattle). Sometimes, this vandalism is accompanied by hateful messages, or else words like "*veneno*" (poison) are written onto the bottles to dissuade its use by desperate border crossers. The vandalism of water and other aid supplies was and remains an ongoing challenge to humanitarian efforts in the Altar Valley. In June 2012, No More Deaths obtained video generated by a hidden wildlife camera that showed a Border Patrol agent destroying a cache of its water along a remote migrant trail.¹ This video was released nationally on PBS, the United States' publicly funded nationwide television network, as part of a series exposing violence, corruption, and impunity within the Border Patrol. In response to the storm of controversy that followed, Richard Barlow, then chief of the US Border Patrol Tucson Sector, issued a memorandum to his agents forbidding interference with No More Deaths and its humanitarian aid supplies. But despite a significant decline in observed incidents of vandalism that July and August, by the autumn of 2012 vandalism had once again become routine, returning to the levels observed prior to the PBS broadcast.

¹ No More Deaths has since released three additional videos showing agents of the US Border Patrol destroying or removing supplies of clean drinking water. The most recent video depicts a lone agent in February 2017 using a knife to slash a cache of water bottles.



Figure 1. Vandalized water gallons at a cache site. Image used with permission from No More Deaths.

In 2015, the authors were approached by No More Deaths to conduct analysis on its desert aid logs to obtain a more robust understanding of vandalism and any identifiable patterns it follows. First, however, the desert aid logs and their 4,847 handmade entries had to be digitized, a process that proceeded with the support of undergraduate interns and additional volunteers. Our subsequent analysis of this archive contributed to a January 2018 human rights report on interference with humanitarian aid (No More Deaths and Coalición de Derechos Humanos 2018). In this report, we observed 415 vandalism events involving 3,586 gallons of water, out of a total of 31,558 gallons distributed during the 46 months between March 2012 and December 2015.

Vandalism occurred at 99 of a total of 141 cache sites regularly visited by No More Deaths volunteers across an 800-square-mile area of the Altar Valley. The scope of vandalism and other forms of petty harassment targeting humanitarian intervention (including surveillance, threats of violence, and the detention and prosecution of humanitarian volunteers for their activities) complicates the use of the concept of “structural violence” to explain harm and mortality along the US–Mexico border (see Slack and Whiteford 2011; Martínez et al. 2014; Giordano and Spradley 2017). First introduced by Galtung (1969), structural violence describes conditions that generate unequal exposure to harm and suffering, in which it remains difficult to identify a direct or immediate perpetrator responsible for this harm.

In contrast, our analysis exposes active and ongoing efforts by state actors to sabotage and prevent humanitarian relief, which increases the harm to which unauthorized border crossers are exposed. To develop a more robust understanding of the implications of these actions for the health and well-being of unauthorized border crossers, we developed a “ruggedness index” (discussed in greater detail below) constructed via GIS modeling to delineate the least difficult paths for arriving at any given cache site, accounting for multiple topographical and climatological variables that cumulatively affect a person’s physiological well-being. This article expands on our analysis by measuring changes in the distribution of water use across No More Deaths’ cache sites, as a proxy for understanding how migration routes have shifted throughout time within this one desert corridor. In 2017, the authors obtained permission from No More Deaths to use their archive for these purposes.

Methodology

In total, No More Deaths’ desert aid logs record 4,847 events involving the caching of water at 512 sites, each assigned a unique GPS coordinate. No More Deaths selects cache sites based principally on observed patterns of movement and water use throughout time, to maximize its availability to those who need it. Additional factors, however, affect the location of cache sites, such as

ensuring their visibility to pedestrians traveling along known migrant trails, while minimizing their visibility from nearby vehicles and hilltops to minimize the risk of vandalism. Finally, No More Deaths coordinates with other humanitarian organizations like the Tucson Samaritans and the Green Valley Samaritans to ensure that their operations do not overlap, thus maximizing the area that these organizations can collectively cover.

Between March 2012 and December 2015, 31,558 one-gallon jugs of clean drinking water in total were distributed across No More Deaths' cache sites.² To measure water use, we subtracted gallons found intact at a given location from the number left behind during the previous visit recorded in the log book. We further accounted for the 3,586 gallons vandalized and 533 gallons with telltale signs of animal damage. This resulted in a total of 27,439 gallons recorded as being used.

To measure changes in the distribution of water use throughout time, we normalized water use data by dividing the total number of gallons used by the number of times No More Deaths visited a given location within a three-month period (January–March, April–June, July–September, and October–December). This provides a value for water use that does not depend on the frequency with which a given site was visited, and that is not skewed by variation in this frequency. In the process, we eliminated any site that was visited five times or fewer (<6) during any given quarter. The majority (87%) of those sites eliminated were experimental sites visited only once or twice to observe whether water was used, while others were added or abandoned based on perceived need. Out of 512 cache sites, we were thus left with a sample of 62 cache sites that were used consistently during all four calendar years.

We then combined the quarterly values for each site to provide an average normalized water use value for each calendar year. The process of data normalization described above allows us to compare rates of water use at the same site between one calendar year and another. Additional variables that might affect the absolute volume of water use at any given site remained constant during this four-year period. These include how visible and exposed a given cache site is, a site's proximity to cache sites serviced by other humanitarian organizations, and a greater availability of potable water from human-created infrastructure near the town sites of Arivaca and Amado (there are no natural sources of potable water within the study area). When combined across sites, this process of data normalization provides a way of measuring changes in the distribution of water use throughout time across all 62 cache sites in the Altar Valley.

Using GIS in the form of spatial analysis of raster grids with 30×30 meter cells, we then generated a score for each cache site that reflects the cumulative difficulty of crossing the desert landscape to arrive at any particular locale (with an assumption that the direction of travel is north). We did so by developing a “ruggedness index” (RI) comprising four parts (Figure 2): temperature (T), vegetation density (V), slope (S), and jaggedness (J). Arizona's Sonoran Desert is responsible for the majority of heat-related deaths in the United States (Harlan et al. 2013), and excessively high temperature stress in the desert has been responsible for the majority of border-related deaths by hyperthermia and dehydration (Doty 2011; Martínez et al. 2013). Dense vegetation increases the time it takes a person to cross the terrain, disorients them, leads migrants to lose their way (Spener 2009), and results in higher energy expenditure by the body (Soule and Goldman 1972). Steeper slopes increase a person's energy costs (Wood and Wood 2006) but also increase a migrant's likelihood of injury from falling. The jagged terrain makes migrants prone to injury, because they are forced to traverse mountain inclines and canyons while lacking appropriate gear or experience (De León 2015).

Temperature was calculated for the month of June 2016 as Land Surface Temperature (LST) using an adjusted remote sensing methodology (Rajeshwari and Mani 2014) requiring Landsat 8 data (Roy et al. 2014). The model uses thermal infrared bands, land surface emissivity, and mathematical functions for average air temperature and humidity for the region to calculate LST (Buettner and Kern 1965; Carlson, Perry, and Schmugge 1990). LST was used as a substitute for local air temperature, which is not readily measurable by remote methods. The month of June was chosen for two reasons. First, it provides the greatest accuracy for measurement of LST due to the least cloud cover in imagery. Second, as previously noted, a majority of fatalities among unauthorized border crossers in Arizona are due to exposure to environmental and climactic extremes. Ruttan et al. (2013) find that the probability of at least one death per day along the Arizona border reaches 50% when peak temperatures rise to 40 °C (104 °F) or higher. As consistently the hottest month in the Arizona desert, June therefore provides the most appropriate data for measuring physiological harm.

Like temperature, we calculated a Normalized Difference Vegetation Index (NDVI) using Landsat imagery to estimate the density of vegetation in the landscape by the formula $(Near\ Infrared - Red) / (Near\ Infrared + Red)$. NDVI detects the reflectance of chlorophyll or green vegetation in a way such that higher numeric values are given for densely vegetated spaces (Rouse et al. 1974).

Slope was calculated using a US Geological Survey (USGS) Digital Elevation Model (DEM) (Gesch 2002). Jaggedness served as a measure of the frequency of change in slope by calculating a focal statistic model in which we calculated the range of slope values in a 90×90 m “window” around every raster cell, our logic being that abrupt changes in slope would be more difficult to traverse than gradual changes and are characteristic of rugged terrain. All variables (T, V, S, and J) were normalized to a range of

²Volunteer and desert aid camp coordinators consulted for this research were firm that data collection during this 46-month period was methodical; although there may be occasional individual errors in the data, we do not believe that there were any cache events left unrecorded.

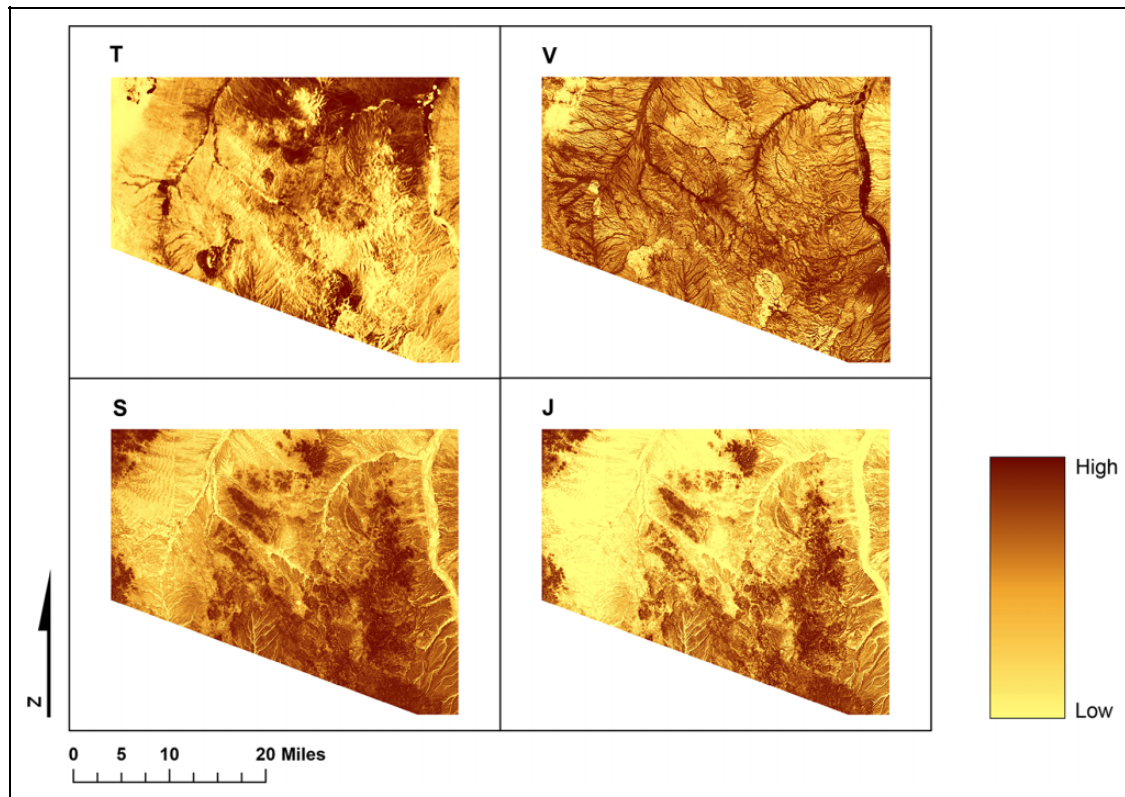


Figure 2. Ruggedness factors in the Altar Valley landscape.

values with a maximum of 1000 using the formula $\left(\frac{\text{value} - \min}{\max - \min} \right) * 1000$. An equally weighted sum of all variables served as the RI in the form of $RI = T + V + S + J$.

We then calculated a cost distance (CD), a non-Euclidean distance, based on the least-accumulative sum of RI values that it would take for a person to reach any point in the landscape from the border (Knaapen, Scheffer, and Harms 1992), and masked it to the extent of the water stations. Our CD was therefore a map of the minimum ruggedness a migrant would be subjected to while traveling north from the US–Mexico border. A Euclidean, or straight-line, distance (ED) was also calculated using the same approach. We normalized the CD using the formula $(CD - ED)/ED$ to compare the values by water station without a bias toward those stations at a greater distance from the border. As shown in Figure 3, this produced a raster surface measuring the ruggedness-based cost that was not dependent on the Euclidean distance from the border, or a relative ruggedness cost distance (RCD). As shown in Figure 4, we then compared the RCD values of cache sites to the levels of water usage by each station for the years 2012–2015.

Findings

As shown in Figure 4, correlation values for RCD and water use were consistently high but increased throughout time, until they were near perfect by the year 2015. In other words, during this four-year period, migrants became more likely to use water at cache sites along more rugged routes of travel, and less likely to use water at cache sites along less rugged routes of travel.

Figure 5 presents a kernel density map of the distribution of water use and RCD for each calendar year from 2012 to 2015. At least within this one migration corridor, during the almost four years reflected in our dataset, our findings reveal that migration has steadily moved toward increasingly difficult routes of travel that require greater physiological exertion for pedestrian transit.

The cumulative impact of this increase can be observed when comparing any given route of transit that bisects one of No More Deaths' water cache sites with a least-cost path (LCP) modeled for the Altar Valley as a whole. Like the ruggedness index above, the LCP is calculated using GIS to model the easiest pedestrian route of transit through a given landscape and the environmental obstacles it contains. Typically, this modeling has been done for purposes of architecture and planning, or else to archeologically reconstruct likely routes of travel between sites (Kong et al. 2010; Taliaferro et al. 2010).

When read through the context of boundary enforcement, a comparison between an LCP and an actual route of travel in the borderlands can only be explained as an outcome of human intervention intended to prevent pedestrian transit or, failing that, to manipulate its geography. Figure 6 provides an example of a diverted LCP (DLCP), a measurement that shows the route most

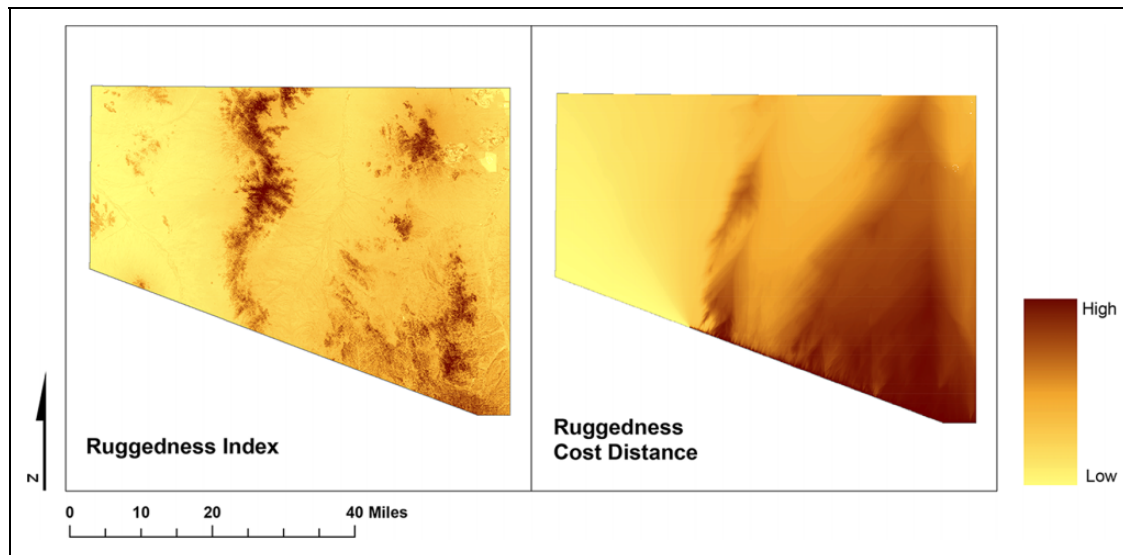


Figure 3. Ruggedness index (RI) and ruggedness cost distance (RCD) for the Altar Valley landscape.

		RCD	Water Use
2012	RCD	1.000	0.796
	Water Use	0.796	1.000
2013	RCD	1.000	0.683
	Water Use	0.683	1.000
2014	RCD	1.000	0.914
	Water Use	0.914	1.000
2015	RCD	1.000	1.000
	Water Use	1.000	1.000

	Minimum	Maximum	Mean	Standard Deviation
RCD	-1	7072.341	883.401	316.011
Water Use	3.34	12.843	6.985	2.258

Figure 4. Correlation values comparing ruggedness cost distance (RCD) value to water use by year.

easily taken while avoiding state intervention, such as exposure to Border Patrol surveillance towers. Considering the US Border Patrol's official policy of weaponizing the desert to increase the hardship encountered by unauthorized migrants (the explicit logic of PTD), the difference between the LCP and DLCP provides a measure of state violence using the friction of terrain to exhaust the bodies of unauthorized migrants to the point of surrender or death.

Discussion

On one hand, our findings reveal that the weaponization of the desert remains an ongoing project reflected in the continuing shift of unauthorized migration toward increasingly difficult routes of travel. Indeed, in previously published work, the authors undertook spatial analysis of the visual range of the Border Patrol's SBInet surveillance program and measured this against the location of recovered human remains both before and after the SBInet program was launched, and we found that in addition to increasing rates

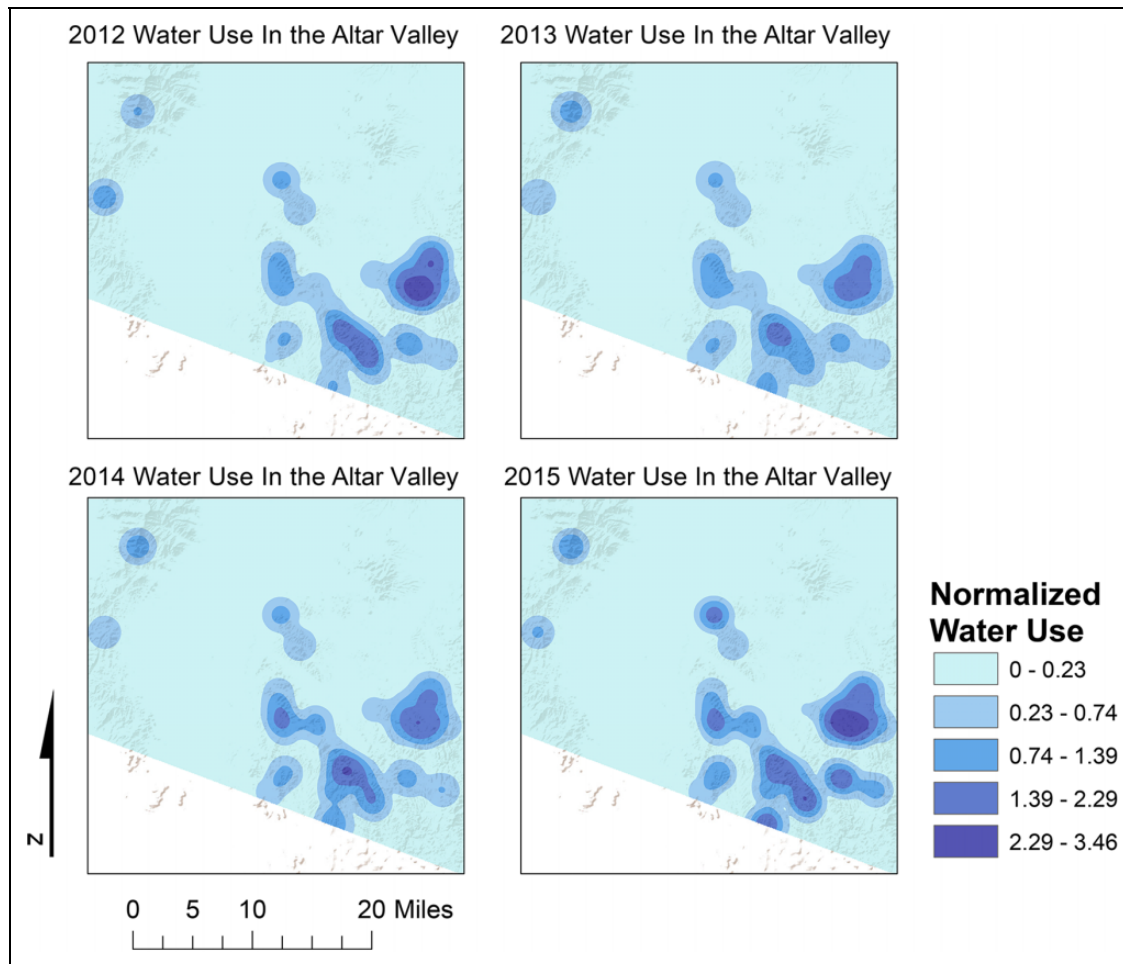


Figure 5. Ruggedness cost distance (RCD) and water use in 2012–2015 in a cross-section of the Altar Valley corridor.

of detection and interdiction, border surveillance infrastructure has the effect of shifting pedestrian routes of transit into areas outside of its visible range (Chambers et al. 2019).

On the other hand, these findings help to contextualize the vandalism regularly observed targeting clean drinking water cached by humanitarian organizations, and the US Border Patrol's interference with humanitarian efforts broadly. Between 2005 and 2018, at least 26 federal cases have been brought against No More Deaths volunteers for efforts undertaken in accordance with the group's mission and protocols. These include three felony prosecutions — the first two were dismissed in 2006 by a federal judge, and the third is pending as of this writing — and almost two dozen citations for caching water on public lands without a permit (see Burridge 2009; Squire 2014). In addition, volunteers report regular forms of harassment that include threats of physical violence and arrest, aggressive interrogation, suggestions that humanitarian volunteers are smugglers or cartel members, detention, suggestive brandishing of firearms, forcing volunteers' vehicles off the road with trucks, surveillance with low-flying helicopters, and following and monitoring volunteers' activities from a distance (discussed at length in No More Deaths and Coalición de Derechos Humanos 2018).

If we understand PTD as an ongoing project that informs everyday enforcement practice, as well as long-term decisions related to the location and expansion of enforcement infrastructure, it becomes easier to understand the cause of and logic behind this harassment and interference with civilian humanitarian efforts. To wit: the efforts of No More Deaths and related humanitarian groups are intended to mitigate the physiological toll of pedestrian transit such that unauthorized migrants are able to survive the increasingly rigorous journey. These efforts run entirely counter to the explicit and observed logic of PTD, insofar as the latter rests on using the physical landscape to maximize the physiological exhaustion faced by unauthorized migrants in the course of their efforts to enter the United States.

The Border Patrol's interference with humanitarian efforts and the ongoing shift of migration into increasingly difficult terrain help to explain the increase in the ratio of deaths compared to the volume of unauthorized migration in the Tucson Sector. In contrast with the literature on "structural violence" along the US–Mexico border (Slack and Whiteford 2011; Martínez et al. 2014;

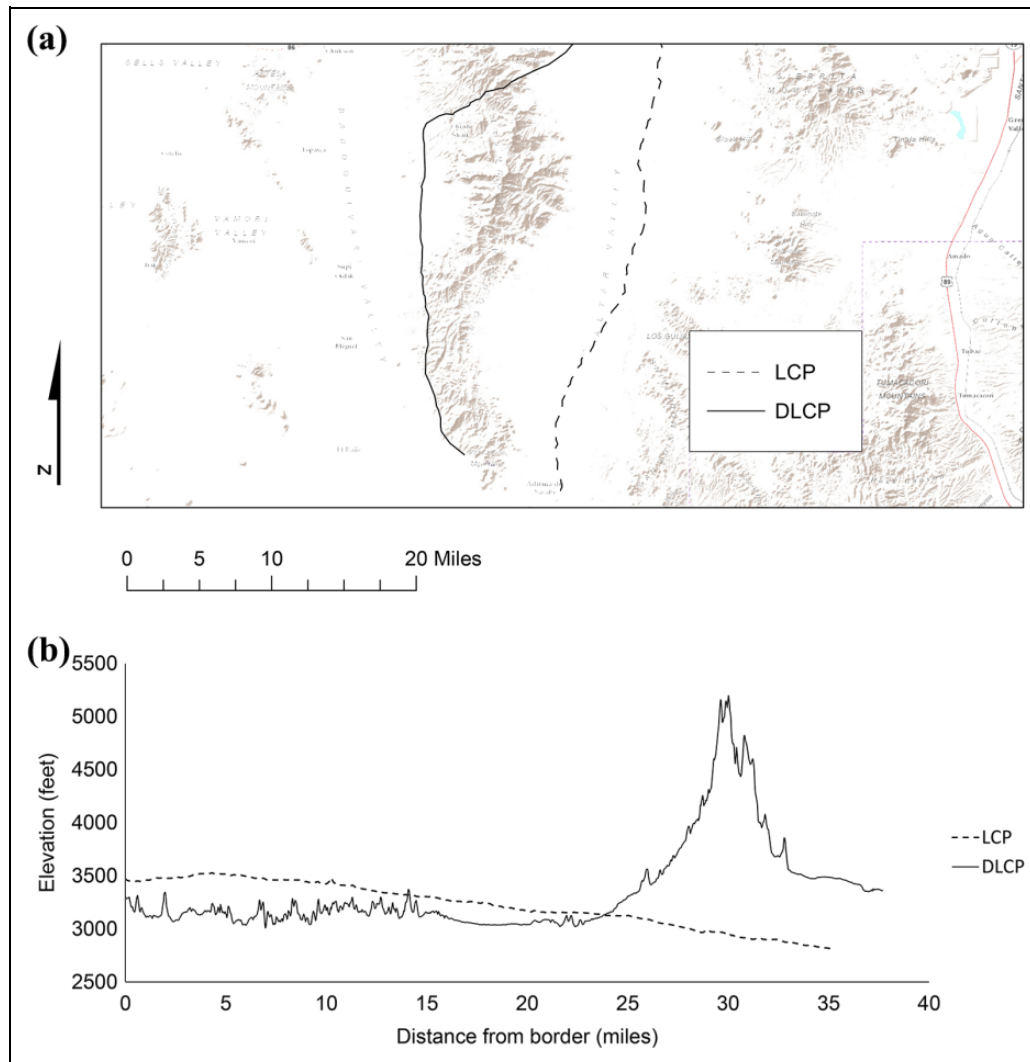


Figure 6. (a) An example of a least-cost path (LCP) and diverted least-cost path (DLCP) for the Altar Valley landscape. (b) Contrasting elevation change profile for LCP and DLCP by distance from border for one cache site.

Giordano and Spradley 2017), this interference also demonstrates active efforts by state actors to increase the physiological harm to which migrants are exposed (Doty 2011). Despite the US government’s assertions to the contrary, death by exposure is not entirely the fault of organized smuggling groups, or a result of purely environmental conditions — and thus beyond anybody’s responsibility or control.

Limitations and Future Directions

By its very nature, unauthorized migration remains undocumented (e.g., unrecorded, and external to official recordkeeping and direct observation). For this reason, there are no measures of the volume of unauthorized migration in a given area or its change throughout time that are not problematic. For example, the Border Patrol has traditionally used apprehension data as a proxy for unauthorized migration (Alden 2017). This measure, however, fails to account for those migrants who successfully evade detection or apprehension in the course of their journey north. A 2013 US Government Accountability Office (GAO) report revealed that the methodology used by the Border Patrol to establish its “effectiveness rate” measurement (based on apprehension data) is deeply flawed and inconsistently applied between its nine southwest border sectors, such that this metric merely “reports on program activity levels and not program results” (GAO 2013).

Meanwhile, the Border Patrol only releases its apprehension data at the aggregate scale of the individual Border Patrol sector, and scholarship attempting to measure shifts in migration either have relied on this data or else have done so across a similarly aggregate scale (e.g., Slack et al. 2016). These studies provide an understanding of shifts in migration flows border-wide, but they

do not provide insight into the geography and conditions of migration *within* a given sector or a specific migration corridor — the microgeographies of migration that respond to and interact with pressures that may include the concentration of enforcement infrastructure and practice.

For all of these reasons, we believe that No More Deaths' desert aid archive provides a remarkable window into the flexibility of migration patterns in one of the busiest corridors for unauthorized migration along the entire US–Mexico border; and our use of this archive to measure changes in the distribution of water use throughout time is a key innovation. We recognize, however, that this measurement also provides an imperfect proxy for migration. It cannot, for example, be assumed that all migrants passing by a water cache access the water. Indeed, No More Deaths volunteers have interviewed repatriated migrants in Nogales, Sonora, who report smugglers telling them not to do so, believing that the water is a trap left by the Border Patrol and used to detect clandestine movement. The data is further affected by vandalism.

Future research could address the shortcomings above by measuring patterns of water use against the location of recovered human remains, and expanding this analysis to additional desert corridors like the Devil's Highway area surrounding Ajo, Arizona, where No More Deaths and Ajo Samaritans also undertake humanitarian work. Meanwhile, reforms to US border policy, such as making detailed spatial information on individual Border Patrol apprehensions available to the public, could produce additional data points that could be used to reconstruct migration patterns and maximize the efficacy of humanitarian intervention.³ In addition, a more serious effort to reduce interference with humanitarian efforts (discussed in the Conclusions and Recommendations section) would also improve the validity of No More Deaths' water use data, while having the much more important outcome of ensuring that water is available to those who need it.

Conclusions and Recommendations

The US–Mexico border is not the only region where states are using environmental features and obstacles to prevent or deter unauthorized migration. At the borders of the European Union, more easily accessible land and sea routes have been shut down, driving dangerous and deadly migration practices across the Atlantic and the Mediterranean (Carling 2007; Van Houtum and Boedeltje 2009; Jones 2016). In this context, EU agencies and member states have also sought to impede and interfere with humanitarian intervention, ranging from petty harassment to criminal prosecution (Institute of Race Relations 2017). Our analysis here in the US–Mexico context helps reveal the logic connecting this interference of humanitarian aid with the weaponization of the environment in borderlands contexts.

From a methodological standpoint, our work signals the need for GIS modeling of human mobility to attend to state violence as a significant and frequently determinant variable. Although much more work could be undertaken modeling the impacts of boundary enforcement on migration routes and practices,⁴ such modeling could also be applied to other contexts in which policing tends to target disproportionately the pedestrian or vehicular mobility of minority populations. This modeling could include, for example, the patchwork of suburban jurisdictions that surround major US cities, where African American and Latinx populations have been subjected to disproportionate traffic stops and quality-of-life citations. It could also include myriad forms of immigration policing removed from the border but that nevertheless constrain peoples' access to transit and circulation through space (Stuesse and Coleman 2014; Boyce 2018).

Returning to the US–Mexico border, it is clear that the Border Patrol's use of the rugged desert as a weapon intended to exhaust the bodies of unauthorized border crossers has created a crucible of death and disappearance in the Arizona–Sonora borderlands. In their report entitled "Disappeared: How U.S. Border Enforcement Agencies Are Fueling a Missing Persons Crisis," No More Deaths and La Coalición de Derechos Humanos (2018) conclude with a list of policy recommendations intended to address widespread vandalism and the Border Patrol's interference with humanitarian aid. These include ending all petty harassment of humanitarian aid workers, prohibiting surveillance of humanitarian aid stations and cache sites, designating the vandalism of humanitarian aid supplies a fireable offense, and documenting and making publicly available all relevant disciplinary records.

We concur with these recommendations. We believe, however, that addressing the suffering caused by current border enforcement practices requires more than just cosmetic reform. At the very least, we recommend that the United States abandon PTD and embrace human well-being and human security as the cornerstones of its border enforcement and immigration policies. This could include the formation of a border-wide agency tasked with search-and-rescue and emergency medical response, one whose mission and operations are restrained by a clear firewall between itself and those of law enforcement. Of course, the Border Patrol does have BORSTAR, an emergency search-and-rescue unit; and it has justified various enforcement initiatives using a "humanitarian"

³ Geoffrey Alan Boyce is a party to litigation attempting to obtain this spatial data, using the US Freedom of Information Act. See *Michigan Immigrant Rights Center, Dr. Geoffrey Alan Boyce, Dr. Elizabeth Oglesby, and American Civil Liberties Union of Michigan v. United States Department of Homeland Security and U.S. Customs and Border Protection*.

⁴ This is particularly the case as enforcement strategies and practices extend deeper into areas of origin and transit, including southern Mexico and northern Africa.

rationale (see Williams 2016). But the continuation of PTD puts such efforts at cross-purposes with the underpinning logic of the agency's enforcement strategy, as reflected in an institutional culture in which vandalism and interference with civilian humanitarian initiatives persist. There is close precedent for the creation of a humanitarian agency with a strict non-law enforcement mandate, like that described above, in the US–Mexico border region — namely, Mexico's reform of Grupos Beta in the early 2000s.

Meanwhile, abandoning PTD as a strategy would not be as radical an undertaking as might be imagined. It has, after all, existed as a guiding nationwide policy only since 1994. Abandoning PTD would remove a significant burden on US taxpayers and on the US judicial system. Without PTD's animating logic, there would be little justification for the extensive walls, infrastructure, and military personnel currently deployed along the US–Mexico border, whose expansion has served as a persistent stumbling block to substantive, much-needed reform of the US immigration system. There would also be much less need for the criminal prosecution of unauthorized border crossers and the family separation that frequently results from the Border Patrol's Consequence Delivery System. Most importantly, abandoning PTD and repositioning human well-being and human security as priorities in US border enforcement would make the border region less chaotic, dangerous, and deadly — for border crossers, border communities, and US authorities alike.

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