REPORT

Addendum to Trail Use Designation Pilot Project Report

Assessment of the Trail Use Designation Pilot Project (TUDPP) on Ecological Resource Conditions in Orange County Parks

Noah Creany M.Sc.[1,2] | Christopher A. Monz PhD[1,2]

[1]Department of Environment & Society, Utah State University, Logan, UT 84321

[2]Ecology Center, Utah State University, Logan, UT 84321

Correspondence
5215 Old Main Hill
Department of Environment & Society,
Utah State University, Logan, UT 84321
Email: noah.creany@usu.edu

Funding information
Natural Communities Coalition,
13042 Old Myford Rd, Irvine, CA 92602
Grant/Award Number: 123459

The Orange County Parks (OC Parks) Trail Use Designation Pilot Project (TUDPP) is an adaptive management strategy that targets evaluating the effectiveness of trail management, reducing conflict, and enhance safety. While there is limited research evaluating the effects of these trail management strategies on the social and ecological dimensions of recreation management in protected areas settings, the TUDPP analysis shows found visitors were generally supportive of activity and directional trail designations and data signaled a trend towards reduced conflicts between users. However, the effect of these strategies on trail ecological resource conditions such as soils and vegetation are not well understood. This report evaluates the effects of the TUDPP trail management strategies on select indicators of trail resource conditions, trail width, and incision. The results of this analysis suggest that direct-management strategies like activity and direction designations on trails can both influence visitor behavior and affect trail resource conditions. This research highlights the challenge of recreation management in protected-area settings where ecological resource conditions are influenced by interactions between management and recreation use, yet also shape the quality of the visitor experience. Collectively, this research underscores the importance of considering the inter-connectivity between management, recreation use, and ecological resource conditions in sustainable protected-area management.

1 | INTRODUCTION

Trail systems area a fundamental recreational component of any Park and Protected Area (PPA) setting. Trails provide access opportunities for a wide range of outdoor recreation activities and can allow visitors to experience nature in a less confined manner. The proper design, maintenance, and management of trails is a primary factor in the overall sustainability of a trail system, and most environmental problems that occur on trails (e.g., erosion, muddy sections, excessive slope) can be mitigated through proper planning of trail location and construction (Hammitt, Cole, & Monz, 2015; Olive & Marion, 2009; Tomczyk & Ewertowski, 2011). Nevertheless, the mode of travel and visitor recreation behavior can also play a substantial role in affecting resource conditions on trails. For example, while complex and situational, numerous studies have generally found that equestrian use results in significantly more erosion on trails than pedestrian or cycling use. In terms of mountain bike use, empirical research suggests that trails frequently used by mountain bikers experience erosion similar to that caused by hiking, except in situations where cycling leads to skids and trail-widening behaviors (Hammitt et al., 2015; Newsome & Davies, 2009; Pickering & Growcock, 2009).

More recent work, using aerial unmanned aerial vehicles (UAVs) or drone imagery and an experimental design, suggests that bicycle impacts develop more rapidly than those from hiking (Martin, Butler, & Klier, 2018). The increased mechanical forces of spinning tires can also dislodge soil leading to increased soil transport, erosion, and vegetation damage, as well as a higher potential for wider and more deeply incised trail conditions and can contribute to downstream effects on water quality. Consequently, managers concerned with sustainable use of trail systems may direct recreation use to certain trail segments where specific modes of travel can be best accommodated safely and sustainably and in a manner that limits potential conflict among visitors. Limiting off-trail use for all modes of travel can significantly reduce overall impacts (Hammitt et al., 2015).

Recreation Ecology, the study of the ecological disturbance created by recreation (Cole, 2021) focuses on the direct disturbance created by recreation users on the structure and function of abiotic and biotic resources such as soils, vegetation, and wildlife. This research has been cataloged in texts such as (Hammitt et al., 2015; Liddle, 1997) which provide the empirical basis for the study of the direct and mechanistic effects of recreation on these ecological resources. Intensive or direct trail management strategies, such as designating the direction of travel and limiting access to certain activity types, are common approaches employed in mixed and multi-use recreation settings to mitigate conflict between trail users and increase perceptions of safety. Although these techniques are widely used in various recreation settings, the effect of these strategies on trail resource conditions is not well understood. The Trail Use Pilot Designation Project (TUDPP) employed direct management strategies described above in three OC Park locations; Aliso and Wood Canyons Wilderness Park, Laguna Coast Wilderness Park, and Santiago Oaks Regional Park. Details related to trail management of individual trails can be found in the TUDPP report.

Monitoring of trail resource conditions has traditionally employed intensive point sampling approaches that require rigorous study design and sampling approaches (e.g., Monz, 2002; Pickering & Growcock, 2009; Tomczyk & Ewertowski, 2013) or rapid assessments of trail networks that can provide general assessments of trail conditions to prescribe trail maintenance (e.g., Eagleston & Marion, 2020; Marion, Wimpey, & Park, 2011; Spernbauer, Monz, D'Antonio, & Smith, 2023). While these methods have been contributed to the understanding of the influence of ecological characteristics such as soil substrate and vegetation cover types and topographic characteristics such as slope, azimuth and alignment with the prevailing landform; however, these approaches can are cost and time intensive and require highly skilled and trained technicians. UAVs present several advantages for ecological monitoring to provide data at relevant spatial and temporal scales to differentiate beteween the naturally occurring dynamics of ecological disturbance and those created by recreational use (Anderson & Gaston, 2013). An considerable advantage of drone trail monitoring is the replicability and repeatability of measurements that can be achieved with the programming of flight parameters using automatic flight planning apps. Although UAVs are a relatively new technology, studies have demonstrated their efficacy and validity for measuring physical conditions such as trail width and incision (Ancin-Murguzur, Munoz, Monz, & Hausner, 2019), as well as for identifying and monitoring informal or undesignated trails (Grubesic & Nelson, 2020).

2 | METHODS

The study design for UAV ecological monitoring of the TUDPP trails complemented the timeline of the trail user survey with flights evaluating "baseline" conditions prior to the implementation of the TUDPP in May 2021 and repeat measurements conducted in 2022. Following the best available practices for UAV use in a protected area setting designated for habitat conservation, the flights were conducted at 30 meters above ground level (AGL) to mitigate the disturbance to raptors and other sensitive avian taxa (Brisson-Curadeau et al., 2017; Vas, Lescroël, Duriez, Boguszewski, & Grémillet, 2015) with linear flight patterns following the trail corridor to provide a predictable direction of movement and efficient data collection.

Flight paths were created by importing the trail layers and segmenting the trail lines at 3-meter intervals to provide adequate overlap between images for photogrammetry processing to create 3-dimensional representations or digital elevation models (DEM) of the trail corridor at a spatial resolution of approximately 1.6cm/pixel GSD (DJI, 2023b) sufficient for the analysis of trail width and incision which are relevant indicators of trail resource conditions. At each 3-meter interval, the DJI Phantom P4 UAV captured images of the trail with a multispectral sensor capable of measuring plant productivity and vigor and ideal for image classification and segmentation (Aber, Marzolff, & Ries, 2010; Lillesand, Kiefer, & Chipman, 2015). The flight paths and parameters were then imported into DJI GSPro (DJI, 2023a), an automatic flight piloting app, to ensure the UAV's location and altitude would be accurate, precise, and consistent for repeat measurements.

Following data collection, processing of the UAV imagery was carried out in Pix4D (*Pix4D Mapper*, 2023) photogrammetry software to generate orthomosaics and a digital terrain model (DTM) of the trail corridor. To evaluate the two indicators of trail resource conditions, (i.e. trail width and incision, or depth) transects were generated across the trail tread at statistically random locations along the trail corridor. These transects were generated at the same locations along a trail between the two years and were then used to collect measurements of trail width and incision. The researchers reviewed the transects to ensure they extended across the trail profile, parallel to the center of the trail, and to the extent of the exposed soil to the edge of trailside vegetation. Calculations of trail incision were collected using a technique adapted from intensive-point sampling protocols where trail depth is measured from a line extending from edge to edge along the trail profile to the deepest point in the trail tread (see Figure 3). Programming software was employed to calculate the measurements of trail width and incision using geospatial packages GeoPandas (Jordahl et al., 2020) and Pandas (Team, 2023), and statistical analysis was carried out using Pingouin (Vallat, 2018) and Seaborn (Waskom, 2021) for figures.

3 | RESULTS

The measurements of trail widths and incision were first evaluated for satisfying the assumptions of normality and homoscedasticity of variances for the statistical tests. The distributions of the data were found to satisfy these assumptions after removing three incision observations that were identified as outliers. Descriptive statistics of mean trail width and incision are tabulated in Table 5 in Appendix A (p. 10).

3.1 | Trail Width

The distributions of trail width measurements between years were visualized with box plots to represent the range and central tendency (i.e. mean) of trail widths (Figure 1). Additional figures for each trail in the analysis can be found in Appendix B.1 (p. 11-15).

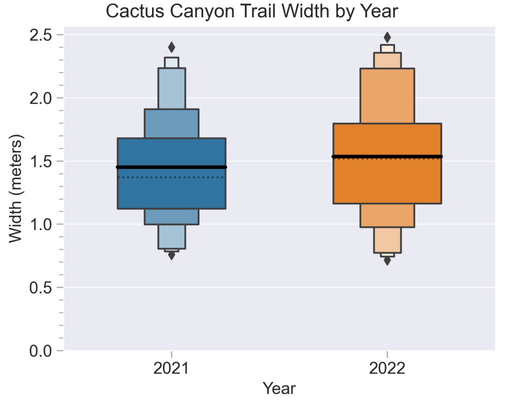

FIGURE 1 Boxplot visualizing the distribution of trail width measurements for Cactus Canyon trail between 2021 and 2022. The mean trail width is represented by the bold line and the median trail width is represented by the thinner, dotted line. Figures for each trail in the analysis can be found in Appendix section B.1

A paired-sample T-Test was performed to evaluate whether there were statistically significant differences in the mean widths of each trail between the two years. The results of this test indicated statistically significant ($p \leq .05$) means in trail width for the Cactus Canyon, Lynx, and Yucca Ridge trails. Cohen's *d*, a measure of the effect size of the difference between the means, suggests a small effect for the Cactus Canyon and Lynx trails and a medium effect for the Yucca Ridge trail.

Next, to evaluate the effect of the TUDPP designations on trail width an analysis of covariance (ANCOVA) was conducted to control for the effects of trail width between years and compare the TUDPP trails against "control" trails not part of the TUDPP (i.e. Grasshopper, Rock-It).

TABLE 1 Paired-samples T-Test of Trail Width Between Years

Trail	T (DF)	p	Cohen's *d*
Cactus Canyon	-2.212(14)	<.05	0.17
Cholla	-1.591(12)	.138	0.1
Chutes Ridgeline	-1.398(12)	.187	0.12
Grasshopper	0.884(14)	.392	0.05
Lynx	-2.973(13)	<.05	0.19
Old Emerald	-1.463(13)	.167	0.12
Peralta Hills	-0.695(14)	.499	0.04
Rock-It	-2.114(13)	.054	0.1
Yucca Ridge	-4.002(14)	<.001	0.61

TABLE 2 ANCOVA for Effects of TUDPP on Trail Width

Source	SS	DF	F	p	np^2
TUDPP	6.099	1	8.645	<.01	.033
Year	5.483	1	7.771	<.01	.03
Resid.	178.504	253	-	-	-

The result of the ANCOVA (Table 2) returned a statistically significant result for the effect of the TUDPP on trail width $F = 8.645(1), p < .001$ with a partial eta-squared (np^2) of 0.03 which indicates a small effect size. To summarize these results, while there were statistically significant differences in the mean widths of Cactus Canyon, Lynx, and Yucca Ridge and between control and TUDPP trails, the interpretation of the effect sizes suggests these differences were small indicating a subtle but measurable change.

3.2 | Trail Incision

The distributions of trail incision measurements between years were visualized with box plots to represent the range and central tendency (i.e. mean) of trail incision (Figure 2). Additional figures for each trail in the analysis can be found in Appendix B.2 (p. 16-20).

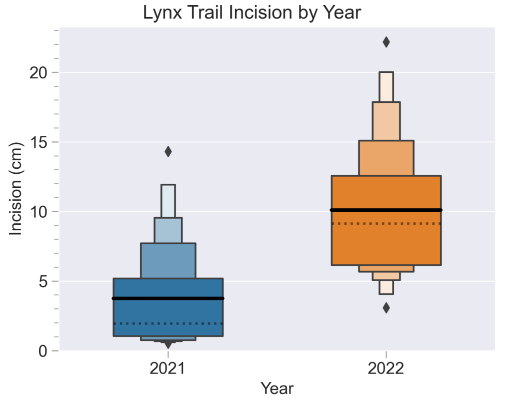

FIGURE 2 Boxplot visualizing the distribution of trail incision measurements for Lynx trail between 2021 and 2022. The mean trail width is represented by the bold line and the median trail width is represented by the thinner, dotted line. Figures for each trail in the analysis can be found in Appendix section B.2

Figure 3 illustrates how the incision measurements were calculated, adapting established intensive-sampling protocols. The blue line is a cross-section of the trail profile, the orange dotted line is the slope from trail edge to edge, and the red dot represents the point of maximum trail incision.

The same statistical procedures were used to evaluate the mean difference in trail incision between the two years. A paired-sample T-test was performed to evaluate the mean differences in trail incision for each trail between years. This test returned statistically significant ($p \leq .05$) differences in mean trail incision between years for the Cactus Canyon, Lynx, and Peralta Hills trails. The positive T value of 3.137 for the Cactus Canyon trail indicates that the mean trail incision decreased from 2021 to 2022. The Cohen's *d* effect sizes for these trails indicate a large effect for the Cactus Canyon and Lynx trails and a moderate effect for the Peralta Hills trail.

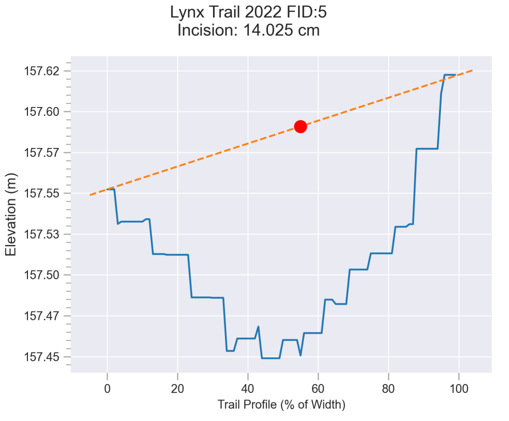

FIGURE 3 Example trail profile and incision measurement along the Lynx trail.

TABLE 3 Paired Samples T-Test of Trail Incision Between Years

Trail	T (DF)	p	Cohen's *d*
Cactus Canyon	3.137(13)	<.001	0.76
Cholla	-1.17(11)	.267	0.37
Chutes Ridgeline	1.499(12)	.160	0.38
Grasshopper	0.418(14)	.682	0.05
Lynx	-4.8(13)	<.001	1.38
Old Emerald	-0.928(13)	.37	0.15
Peralta Hills	-2.797(14)	<.05	0.44
Rock-It	-0.283(12)	.782	0.09
Yucca Ridge	-0.34(13)	.739	0.06

Next, an ANCOVA test was conducted to control for variation between years and determine the effect of the TUDPP designation on mean trail incision by comparing TUDPP trails against control trails (i.e. Grasshopper and Rock-It).

TABLE 4 ANCOVA for Effects of TUDPP on Trail Incision

Source	SS	DF	F	p	np^2
TUDPP	469.27	1	10.52	<.001	0.041
Year	191.89	1	4.323	<.05	0.017
Residual	11155.9	249	-	-	-

The test of the ANCOVA (Table 4) returned a statistically significant result, $F = 10.516(1), p < .001$, with a partial-eta-squared (np^2) of 0.04 which can be interpreted as a small effect size. Taken together, these results indicate there were statistically significant differences in mean trail incision measurements between years for three of the TUDPP trails. When controlling for this difference between years, we found a small but measurable effect of the TUDPP trail designation on mean trail incision measurements which was greater than the variation in measurements between years.

4 | DISCUSSION

Intensive, direct trail management strategies like the TUDPP are effective in mitigating conflicts between users and increasing perceptions of safety. Importantly, as noted in the TUDPP report, these trail management strategies can also introduce new or alter visitor behaviors, such as shifts in the direction of trail use, as well as increases in trail speed, and potential "spillover" effects on control trails or those not part of the TUDPP. The results of this analysis found statistically significant differences in trail width and incision for a subset of the TUDPP trails with some control trails approaching the level of statistical significance (e.g. Rock-It Trail's width). However, there are two important points to take into consideration to put these results into context.

First, statistics provide an objective comparison of data to identify meaningful trends, but statistical significance does not equate or amount to the managerial significance of these results. Many of the significant results had small to moderate effect sizes where the differences in mean trail width were between 0.08m/3.15 inches (e.g., Cactus Canyon, Lynx Trails) and 0.22m/8.66 inches (e.g. Yucca Ridge Trail). The significant results for the difference in mean trail incision with moderate to large effect sizes ranged from -4.84cm/-1.91 inches (Cactus Canyon) to 2.53cm/0.99 inches (Peralta Hills) and 6.36cm/2.53 inches (Lynx). Collectively, although these results represent statistically significant change, they may not exceed managerially relevant thresholds or standards of change in resource conditions to alter the course of management or trigger management action.

Second, this analysis relies on comparisons between two monitoring efforts separated by only on year. Oftentimes, meaningful and measurable ecological change requires extended, multi-year periods of monitoring to stabilize natural variation (e.g. drought or seasonal weather patterns) that may influence conditions. Additionally, the control trails in the analysis were selected independently from the TUDPP planning, and may not have fully represented the range of trails and conditions as those in the TUDPP, and maintenance on the Lizard Trail (Laguna Coast Wilderness Park), a control trail in the analysis, precluded repeat measurements which further limited the representativeness of the control trails.

Notwithstanding these limitations, the results of this analysis offer considerations for managers in using trail management strategies like the TUDPP. The trends in this analysis suggest that direct-management strategies like activity and direction designations on trails can both influence visitor behavior and affect trail resource conditions. For example, with respect to changes in visitor behavior, we found that TUDPP downhill-only mountain bike trail designations resulted in statistically significant increases in trail speeds. In this analysis, we found a subtle but consistent signal that on the whole, TUDPP trail designations can contribute to wider and more deeply incised trail conditions. However, given the amount of unexplained variance (i.e., residuals) in the trail width and incision ANCOVA models, other factors like trail slope, prevailing slope alignment, and design characteristics likely have a more significant influence on trail conditions than those observed from TUDPP designation. Nevertheless, when these results are taken together, this captures the challenge of recreation management in protected-area settings like the OC Parks trails included in the Central and Coastal Orange County Natural Community Conservation Plan/Habitat Conservation Plan (NCCP/HCP) (CDFW, 2022), where recreation use must be balanced with habitat and conservation goals. Study results illustrate the interdependent relationships between the quality of the visitor experience (i.e. conflict, safety) and ecological resource conditions (i.e. trail width, incision) as a function of the management strategies for recreation use (i.e. TUDPP management). This underscores the importance of considering these interactions between management, recreation use, and ecological resource conditions for the sustainability of parks and protected areas. Furthermore, when trail management strategies like those in the TUDPP are employed, a program of monitoring of trail resource conditions that is responsive to managerially-relevant change would help inform adaptive management decision making.

References

Aber, J. S., Marzolff, I., & Ries, J. B. (2010). *Small-format aerial photography: principles, techniques and geoscience applications* (1. ed ed.). Amsterdam: Elsevier. (OCLC: 700521771)

Ancin-Murguzur, F. J., Munoz, L., Monz, C. A., & Hausner, V. H. (2019, September). Drones as a tool to monitor human impacts and vegetation changes in parks and protected areas. *Remote Sensing in Ecology and Conservation*, *0*(0). Retrieved 2019-10-04, from https://doi.org/10.1002/rse2.127 doi: 10.1002/rse2.127

Anderson, K., & Gaston, K. J. (2013, April). Lightweight unmanned aerial vehicles will revolutionize spatial ecology. *Frontiers in Ecology and the Environment*, *11*(3), 138–146. Retrieved 2023-08-05, from https://onlinelibrary.wiley.com/doi/abs/10.1890/120150 (_eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1890/120150) doi: 10.1890/120150

Brisson-Curadeau, E., Bird, D., Burke, C., Fifield, D. A., Pace, P., Sherley, R. B., & Elliott, K. H. (2017, December). Seabird species vary in behavioural response to drone census. *Scientific Reports*, *7*(1), 17884. Retrieved 2021-01-14, from https://www.nature.com/articles/s41598-017-18202-3 (Number: 1 Publisher: Nature Publishing Group) doi: 10.1038/s41598-017-18202-3

CDFW. (2022). *Central Coastal NCCP/HCP.* Retrieved 2022-08-16, from https://wildlife.ca.gov/Conservation/Planning/NCCP/Plans/Orange-Coastal

Cole, D. N. (2021, May). Reflections on the early history of recreation ecology. *Parks Stewardship Forum*, *37*(2). Retrieved 2022-03-04, from https://escholarship.org/uc/item/5wv0m2m3 doi: 10.5070/P537253243

DJI. (2023a). *DJI GSPro.* Shenzhen, China: Author.

DJI. (2023b). *P4 Multispectral - Specifications - DJI.* Retrieved 2023-08-07, from https://www.dji.com/p4-multispectral/specs

Eagleston, H., & Marion, J. L. (2020, June). Application of airborne LiDAR and GIS in modeling trail erosion along the Appalachian Trail in New Hampshire, USA. *Landscape and Urban Planning*, *198*, 103765. Retrieved 2020-03-03, from https://linkinghub.elsevier.com/retrieve/pii/S016920461931059X doi: 10.1016/j.landurbplan.2020.103765

Grubesic, T. H., & Nelson, J. R. (2020). Detecting and Monitoring Informal Trails in an Urban Mountain Preserve Using Small Unmanned Aerial Systems. In T. H. Grubesic & J. R. Nelson (Eds.), *UAVs and Urban Spatial Analysis: An Introduction* (pp. 165–187). Cham: Springer International Publishing. Retrieved 2020-12-30, from https://doi.org/10.1007/978-3-030-35865-5_9 doi: 10.1007/978-3-030-35865-5_9

Hammitt, W. E., Cole, D. N., & Monz, C. A. (2015). *Wildland Recreation: Ecology and Management* (third ed ed.). Hoboken, N.J: John Wiley & Sons.

Jordahl, K., Bossche, J. V. D., Fleischmann, M., Wasserman, J., McBride, J., Gerard, J., … Leblanc, F. (2020, July). *GeoPandas.* Zenodo. Retrieved 2023-08-07, from https://zenodo.org/record/3946761 doi: 10.5281/ZENODO.3946761

Liddle, M. (1997). *Recreation Ecology: The Ecological Impact of Outdoor Recreation* (No. no.8). London: Chapman and Hall.

Lillesand, T. M., Kiefer, R. W., & Chipman, J. W. (2015). *Remote sensing and image interpretation* (Seventh edition ed.). Hoboken, N.J: John Wiley & Sons, Inc.

Marion, J. L., Wimpey, J. F., & Park, L. O. (2011). The science of trail surveys: Recreation ecology provides new tools for managing wilderness trails. *Park Sci*, *28*(3), 60–65.

Martin, R. H., Butler, D. R., & Klier, J. (2018, December). The influence of tire size on bicycle impacts to soil and vegetation. *Journal of Outdoor Recreation and Tourism*, *24*, 52–58. Retrieved 2022-06-17, from https://www.sciencedirect.com/science/article/pii/S2213078018300409 doi: 10.1016/j.jort.2018.08.002

Monz, C. A. (2002, February). The response of two arctic tundra plant communities to human trampling disturbance. *Journal of Environmental Management*, *64*(2), 207–217. Retrieved 2023-08-05, from https://www.sciencedirect.com/science/article/pii/S0301479701905249 doi: 10.1006/jema.2001.0524

Newsome, D., & Davies, C. (2009, December). A case study in estimating the area of informal trail development and associated impacts caused by mountain bike activity in John Forrest National Park, Western Australia. *Journal of Ecotourism*, *8*(3), 237–253. Retrieved 2019-09-30, from http://www.tandfonline.com/doi/abs/10.1080/14724040802538308 doi: 10.1080/14724040802538308

Olive, N. D., & Marion, J. L. (2009, March). The influence of use-related, environmental, and managerial factors on soil loss from recreational trails. *Journal of Environmental Management*, *90*(3), 1483–1493. Retrieved 2019-10-04, from https://linkinghub.elsevier.com/retrieve/pii/S0301479708002867 doi: 10.1016/j.jenvman.2008.10.004

Pickering, C. M., & Growcock, A. J. (2009, November). Impacts of experimental trampling on tall alpine herbfields and subalpine grasslands in the Australian Alps. *Journal of Environmental Management*, *91*(2), 532–540. Retrieved 2023-08-05, from https://linkinghub.elsevier.com/retrieve/pii/S0301479709003260 doi: 10.1016/j.jenvman.2009.09.022

Pix4D Mapper. (2023). Prilly, Switzerland: Pix4D S.A. Retrieved from https://pix4d.com

Spernbauer, B. S., Monz, C., D'Antonio, A., & Smith, J. W. (2023, March). Factors influencing informal trail conditions: Implications for management and research in Urban-Proximate parks and protected areas. *Landscape and Urban Planning*, *231*, 104661. Retrieved 2023-08-05, from https://linkinghub.elsevier.com/retrieve/pii/S0169204622003103 doi: 10.1016/j.landurbplan.2022.104661

Team, P. D. (2023, June). *Pandas*. Zenodo. Retrieved 2023-08-07, from https://zenodo.org/record/3509134 doi: 10.5281/ZENODO.3509134

Tomczyk, A. M., & Ewertowski, M. (2011, January). Degradation of recreational trails, Gorce National Park, Poland. *Journal of Maps*, *7*(1), 507–518. Retrieved 2019-10-04, from http://www.tandfonline.com/doi/abs/10.4113/jom.2011.1195 doi: 10.4113/jom.2011.1195

Tomczyk, A. M., & Ewertowski, M. (2013, June). Planning of recreational trails in protected areas: Application of regression tree analysis and geographic information systems. *Applied Geography*, *40*, 129–139. Retrieved 2023-08-05, from https://www.sciencedirect.com/science/article/pii/S0143622813000556 doi: 10.1016/j.apgeog.2013.02.004

Vallat, R. (2018, November). Pingouin: statistics in Python. *Journal of Open Source Software*, *3*(31), 1026. Retrieved 2023-08-07, from http://joss.theoj.org/papers/10.21105/joss.01026 doi: 10.21105/joss.01026

Vas, E., Lescroël, A., Duriez, O., Boguszewski, G., & Grémillet, D. (2015). Approaching birds with drones: first experiments and ethical guidelines. *Biology letters*, *11*(2), 20140754. (ISBN: 1744-9561 Publisher: The Royal Society) doi: 10.1098/rsbl.2014.0754

Waskom, M. (2021, April). seaborn: statistical data visualization. *Journal of Open Source Software*, *6*(60), 3021. Retrieved 2022-11-07, from https://joss.theoj.org/papers/10.21105/joss.03021 doi: 10.21105/joss.03021

A | SUPPLEMENTARY TABLES

TABLE 5 Descriptive Statistics for Trail Width and Incision Between Years

Trail	Year	Width (m)		Incision (cm)	
		Mean	Difference	Mean	Difference
Cactus Canyon	2021	1.451	-	15.569	-
	2022	1.535	0.08	10.734	-4.84
Cholla	2021	1.772	-	10.497	-
	2022	1.835	0.06	12.707	2.21
Chutes Ridgeline	2021	1.193	-	2.687	-
	2022	1.250	0.06	1.741	-0.95
Grasshopper[1]	2021	2.370	-	5.655	-
	2022	2.322	-0.05	5.379	-0.28
Lynx	2021	1.458	-	3.744	-
	2022	1.540	0.08	10.102	6.36
Old Emerald	2021	1.468	-	7.773	-
	2022	1.537	0.07	8.833	1.06
Peralta Hills	2021	2.373	-	12.349	-
	2022	2.417	0.04	14.882	2.53
Rock-It[1]	2021	1.969	-	4.21	-
	2022	2.096	0.13	3.391	-0.82
Yucca Ridge	2021	1.440	-	3.638	-
	2022	1.665	0.22	3.889	0.25

[1] Control trail in analysis.

B | SUPPLEMENTARY FIGURES

B.1 | Trail Width Figures

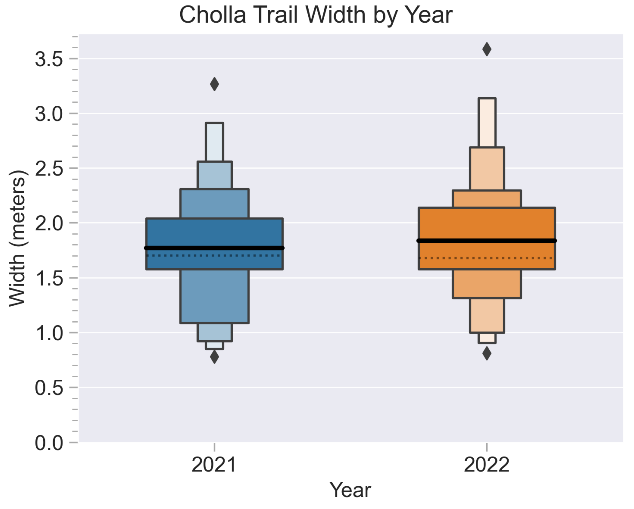

FIGURE 4 Drone measurements of Cholla trail (Aliso and Wood Canyons Wilderness Park) width (m) between 2021 and 2022. The mean (average) width is represented by the bold black bar and the median is indicated by the dotted gray line.

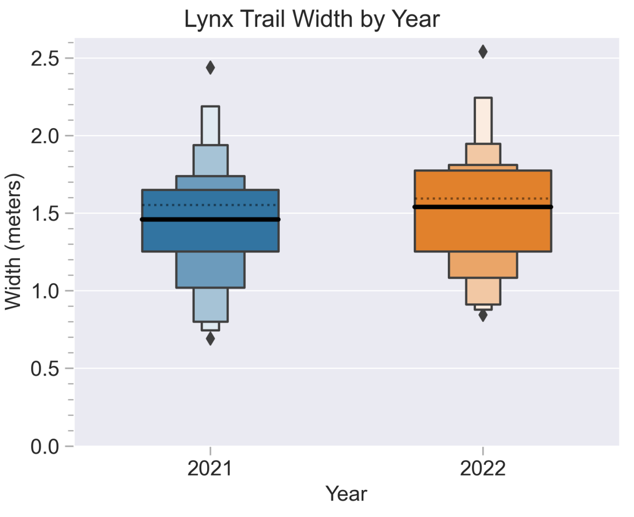

FIGURE 5 Drone measurements of Lynx trail (Aliso and Wood Canyons Wilderness Park) width (m) between 2021 and 2022. The mean (average) width is represented by the bold black bar and the median is indicated by the dotted gray line.

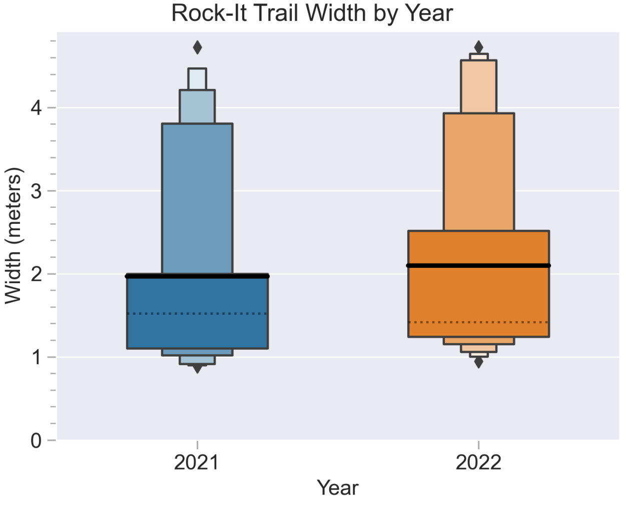

FIGURE 6 Drone measurements of Rock-It trail (**Control**) (Aliso and Wood Canyons Wilderness Park) width (m) between 2021 and 2022. The mean (average) width is represented by the bold black bar and the median is indicated by the dotted gray line.

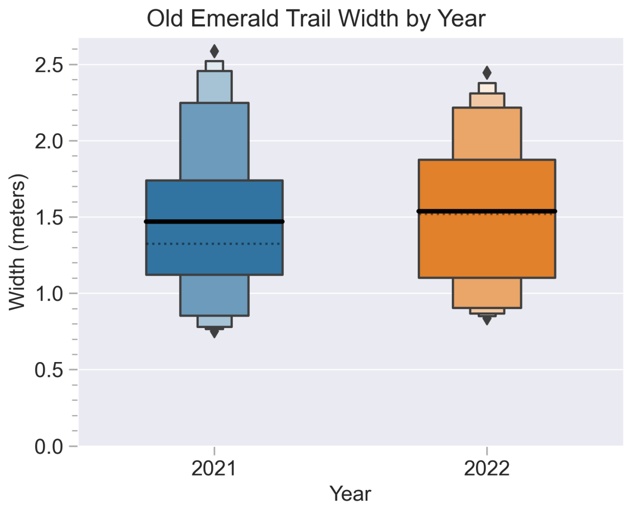

FIGURE 7 Drone measurements of Old Emerald trail (Laguna Coast Wilderness Park) width (m) between 2021 and 2022. The mean (average) width is represented by the bold black bar and the median is indicated by the dotted gray line.

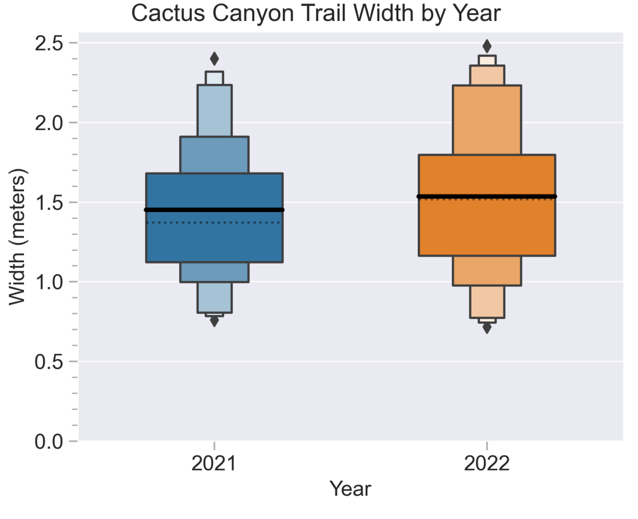

FIGURE 8 Drone measurements of Cactus Canyon trail (Santiago Oaks Regional Park) width (m) between 2021 and 2022. The mean (average) width is represented by the bold black bar and the median is indicated by the dotted gray line.

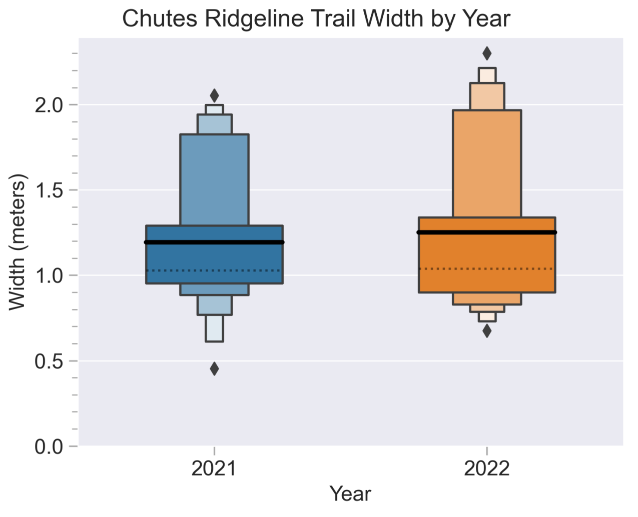

FIGURE 9 Drone measurements of Chutes Ridgeline trail (Santiago Oaks Regional Park) width (m) between 2021 and 2022. The mean (average) width is represented by the bold black bar and the median is indicated by the dotted gray line.

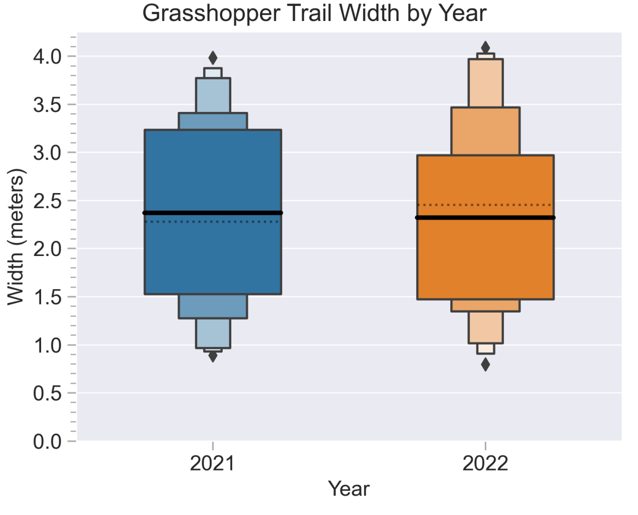

FIGURE 10 Drone measurements of Grasshopper trail (Santiago Oaks Regional Park) width (m) between 2021 and 2022. The mean (average) width is represented by the bold black bar and the median is indicated by the dotted gray line.

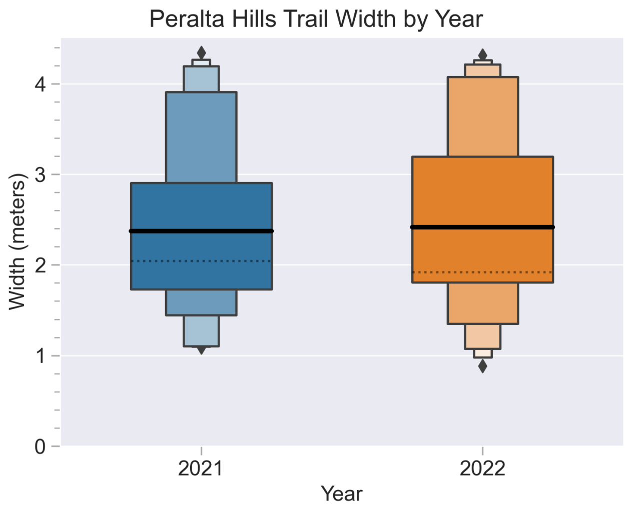

FIGURE 11 Drone measurements of Peralta Hills trail (Santiago Oaks Regional Park) width (m) between 2021 and 2022. The mean (average) width is represented by the bold black bar and the median is indicated by the dotted gray line.

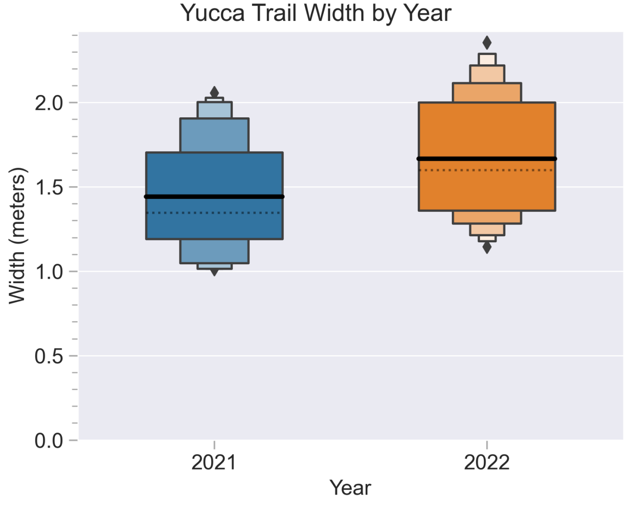

FIGURE 12 Drone measurements of Yucca Ridge trail (Santiago Oaks Regional Park) width (m) between 2021 and 2022. The mean (average) width is represented by the bold black bar and the median is indicated by the dotted gray line.

B.2 | Trail Incision Figures

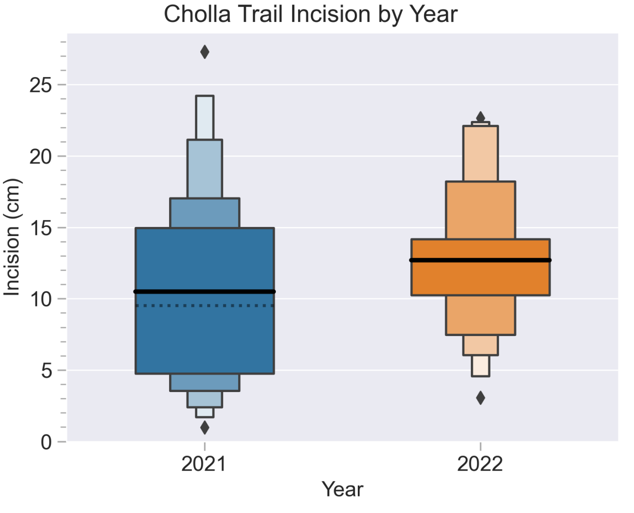

FIGURE 13 Drone measurements of Cholla trail (Aliso and Wood Canyons Wilderness Park) incision (cm) between 2021 and 2022. The mean (average) width is represented by the bold black bar and the median is indicated by the dotted gray line.

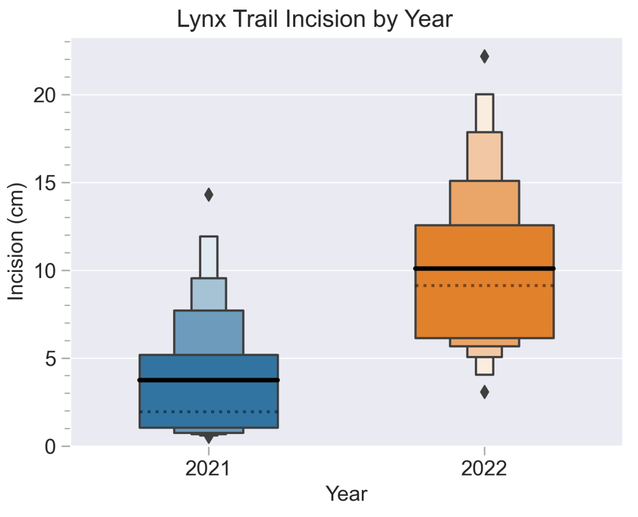

FIGURE 14 Drone measurements of Lynx trail (Aliso and Wood Canyons Wilderness Park) incision (cm) between 2021 and 2022. The mean (average) width is represented by the bold black bar and the median is indicated by the dotted gray line.

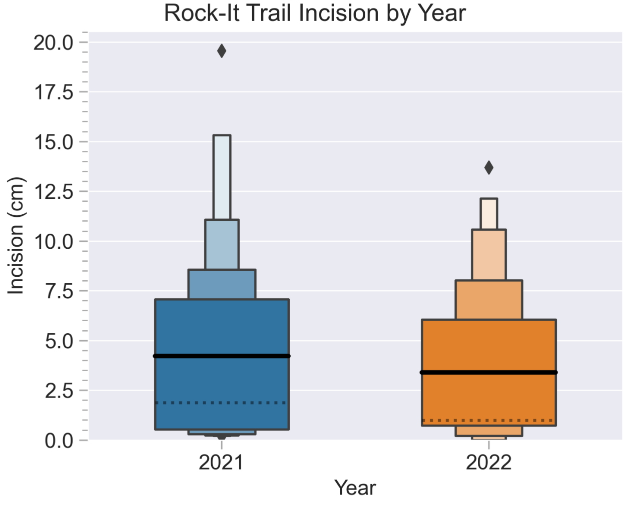

FIGURE 15 Drone measurements of Rock-It trail (**Control**) (Aliso and Wood Canyons Wilderness Park) incision (cm) between 2021 and 2022. The mean (average) width is represented by the bold black bar and the median is indicated by the dotted gray line.

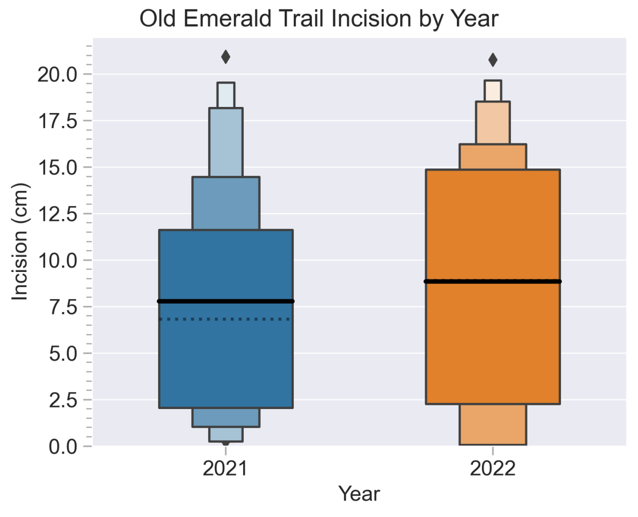

FIGURE 16 Drone measurements of Old Emerald trail (Laguna Coast Wilderness Park) incision (cm) between 2021 and 2022. The mean (average) width is represented by the bold black bar and the median is indicated by the dotted gray line.

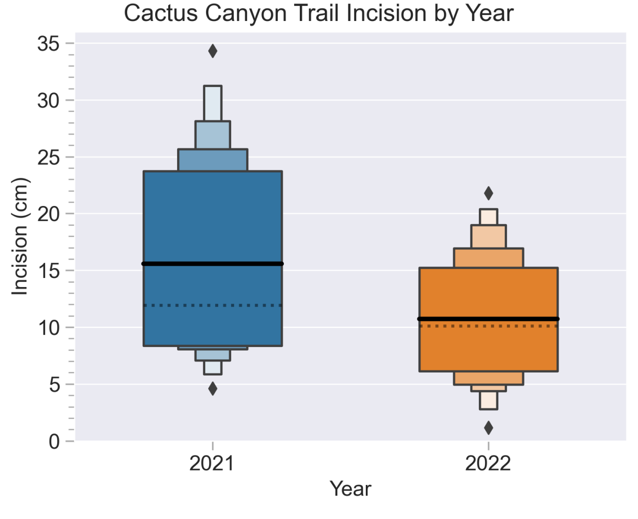

FIGURE 17 Drone measurements of Cactus Canyon trail (Santiago Oaks Regional Park) incision (cm) between 2021 and 2022. The mean (average) width is represented by the bold black bar and the median is indicated by the dotted gray line.

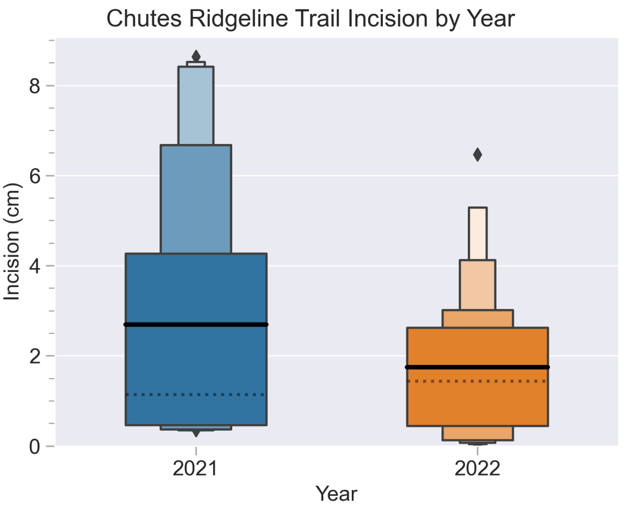

FIGURE 18 Drone measurements of Chutes Ridgeline trail (Santiago Oaks Regional Park) incision (cm) between 2021 and 2022. The mean (average) width is represented by the bold black bar and the median is indicated by the dotted gray line.

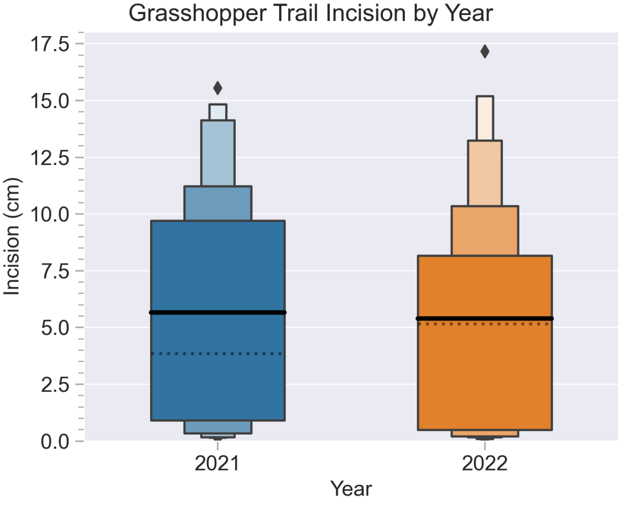

FIGURE 19 Drone measurements of Old Emerald trail (**Control**) (Santiago Oaks Regional Park) incision (cm) between 2021 and 2022. The mean (average) width is represented by the bold black bar and the median is indicated by the dotted gray line.

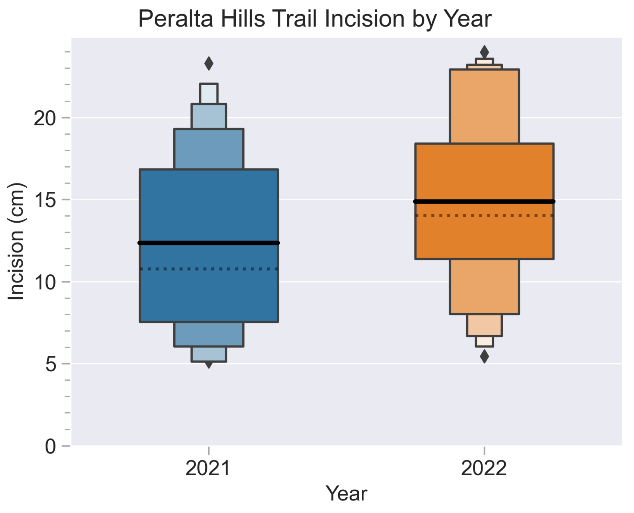

FIGURE 20 Drone measurements of Peralta Hills trail (Santiago Oaks Regional Park) incision (cm) between 2021 and 2022. The mean (average) width is represented by the bold black bar and the median is indicated by the dotted gray line.

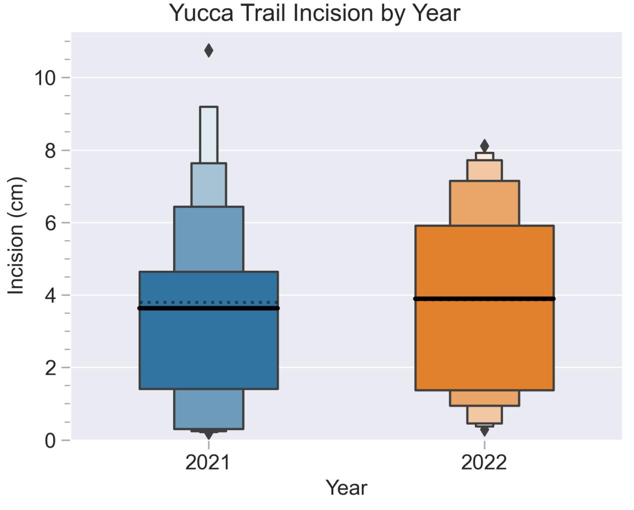

FIGURE 21 Drone measurements of Yucca Ridge trail (Santiago Oaks Regional Park) incision (cm) between 2021 and 2022. The mean (average) width is represented by the bold black bar and the median is indicated by the dotted gray line.