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Source: Air, Soil and Water Research, 13(1)

Published By: SAGE Publishing

URL: https://doi.org/10.1177/1178622120950272

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Wildfire Risk and Hazardous Fuel Reduction Treatments Along the US-Mexico Border: A Review of the Science (1986-2019)

Air, Soil and Water Research
Volume 13: 1–7
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DOI: 10.1177/1178622120950272

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ABSTRACT: The ecosystems along the border between the United States and Mexico are at increasing risk to wildfire due to interactions among climate, land-use, and fuel loads. A wide range of fuel treatments have been implemented to mitigate wildfire and its threats to valued resources, yet we have little information about treatment effectiveness. To fill critical knowledge gaps, we reviewed wildfire risk and fuel treatment studies that were conducted near the US-Mexico border and published in the peer-reviewed literature between 1986 and 2019. The number of studies has grown during this time in warm desert to forest ecosystems on primarily federal lands. The most common study topics included fire effects on native species, the role of invasive species and woody encroachment on wildfire risk, historical fire regimes, and remote sensing and modeling to study wildfire risk across the landscape. A majority of fuel treatment studies focused on prescribed burns, and fuel treatments collectively had mixed effects on mitigating future wildfire risk and threats to ecosystems depending on vegetation and fire characteristics. The diversity of ecosystems and land ownership along the US-Mexico border present unique challenges for understanding and managing wildfire risk, and also create opportunities for collaboration and cross-site studies to promote knowledge across broad environmental gradients.

KEYWORDS: Arid lands, invasive species, mechanical treatments, prescribed fire, southwestern United States, woody encroachment

RECEIVED: May 19, 2020. **ACCEPTED:** July 24, 2020.

TYPE: Case Studies of a Grassroots Binational Restoration Collaborative in the Madrean Archipelago Ecoregion (2014-2019)-Concise Review

FUNDING: The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This review was funded by the Department of the Interior Office of Wildland Fire and the USGS Ecosystems Mission Area.

DECLARATION OF CONFLICTING INTERESTS: The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Introduction

The border region between the United States and Mexico contains desert scrub to montane forest ecosystems with different wildfire histories due to variation in their climates, topographic features, fuel loads, and land-uses.[1,2] Over the past several decades, fire suppression, woody plant encroachment, spread of non-native invasive species, and aridification have interacted to increase wildfire frequency and severity.[3–5] High fuel loads and catastrophic wildfire threaten human life and infrastructure, degrade wildlife habitat, and imperil natural and cultural resources.[6] Fuel treatments that include prescribed fire, managed wildfire, mechanical fuel reduction, herbicide application, and livestock grazing have been historically implemented throughout the border region to reduce wildfire risk, improve ecosystem condition, and increase the safety and security of border operations. A recent example of these efforts is the Southern Border Fuels Management Initiative, which was initiated in 2017 to conduct fuel treatments across 1,300 kilometers of Department of the Interior (DOI) lands along the US-Mexico border.[7]

Despite large investments in fuel treatments, our knowledge about the effectiveness of treatments to reduce fuel loads, mitigate wildfire risk, and improve ecosystem health remains limited. Enhanced understanding about treatment effectiveness and resulting changes to wildfire risk and ecosystem condition can improve future efforts in face of a growing wildfire threat in the coming decades. We addressed this important information gap by conducting a literature review of fuel treatment and wildfire risk studies in ecosystems that occur along the US-Mexico border over the past 34 years. The goal of our review was to determine (1) when and where along the border wildfire and fuel treatment studies have taken place, and (2) the current state of knowledge on wildfire and fuel treatments along the border and important information gaps that can be filled with future research.

Methods

In January 2020, the lead author searched the Web of Science Core Collection from the years 1986 to 2019 using a combination of terms that included locations and ecosystems near the US-Mexico border, along with keywords such as "fire" and "risk." While the US-Mexico border region is often defined by an area that covers 100 km in either direction from the international border,[8] we included studies if they occurred within an ecosystem that fell within this area, but the study site was geographically further away. To find studies that examined fuel treatments, keywords such as "fuel* treatment*," "prescribed fire," "mechanical thinning," "mastication," and "herbicide" were included. Studies were excluded if they were conducted in regions outside the southwestern United States and northern Mexico or if their focus was not on relevant ecosystems or fire-related topics. Sixty different keyword searches were initially performed, but only 19 searches returned 90 useable studies published in peer-reviewed papers selected for this review.

Selected studies were categorized by the year of publication, location, ecoregion, land ownership, topic of study, and fuel

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treatments used where the study took place. We mapped the locations of the studies using information available from coordinates, figures, or written descriptions. We calculated the number of studies in each category relative to the total number of studies and summed the number of publications that occurred in 5-year intervals from 1986 to 2019. We extracted and summarized relevant information from the studies by topic, which fell under the wildfire risk and fuel treatment theme of the review.

Results and Discussion

The number of publications on wildfire risk and fuel treatments in ecosystems that occur along the US-Mexico border has increased over the last 34 years from 5 studies (6% of the total number of 90 selected studies) published between 1986 and 1999 to 30 (33% of total) published between 2015 and 2019 (Figure 1). Forty-two percent of the 90 selected studies focused on wildfire risk and fuel treatments in ecosystems along the US-Mexico border were conducted in Arizona, 18% in New Mexico, 10% in California, 5% in Texas, and 1% in Mexico, whereas 20% took place across multiple states, and 4% were conducted in nonborder states within ecosystems that extend to the border region (ie, the Mojave Desert in southern Nevada) (Figures 2 and 3A). Twenty-four percent of the selected studies were conducted in the Chihuahuan Desert, 21% were based in the Sonoran Desert, 17% were in the Mojave Desert, 25% were in the Madrean Archipelago (Sky Island mountain ecoregion of southeastern Arizona and southwestern New Mexico) and other forested ecoregions of the Southwest, and 13% were conducted in other ecoregions or across multiple ecoregions (Figure 3B). Most studies were conducted on federal lands (85%), and of those federal studies, 43% were conducted on DOI lands, 25% occurred on US Department of Agriculture lands, 5% were on lands managed by the Department of Defense, and 12% were conducted on lands managed by multiple or other agencies (Figure 3C). Thirty-four studies addressed fuel treatments, and within these studies, 65% examined prescribed fire, 12% looked at mechanical treatments (thinning, pile and burn, hand-pulling of invasive

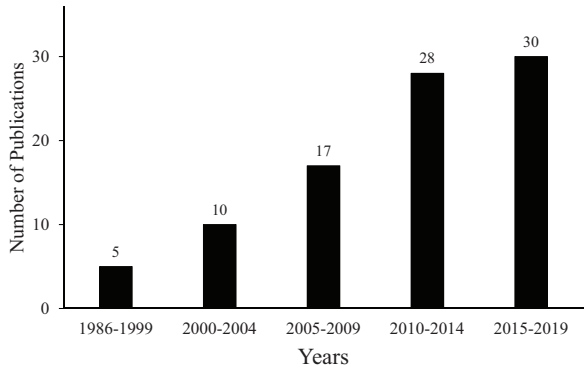


Figure 1. The number of studies that address wildfire risk and fuel reduction treatments along the US-Mexico border through time.

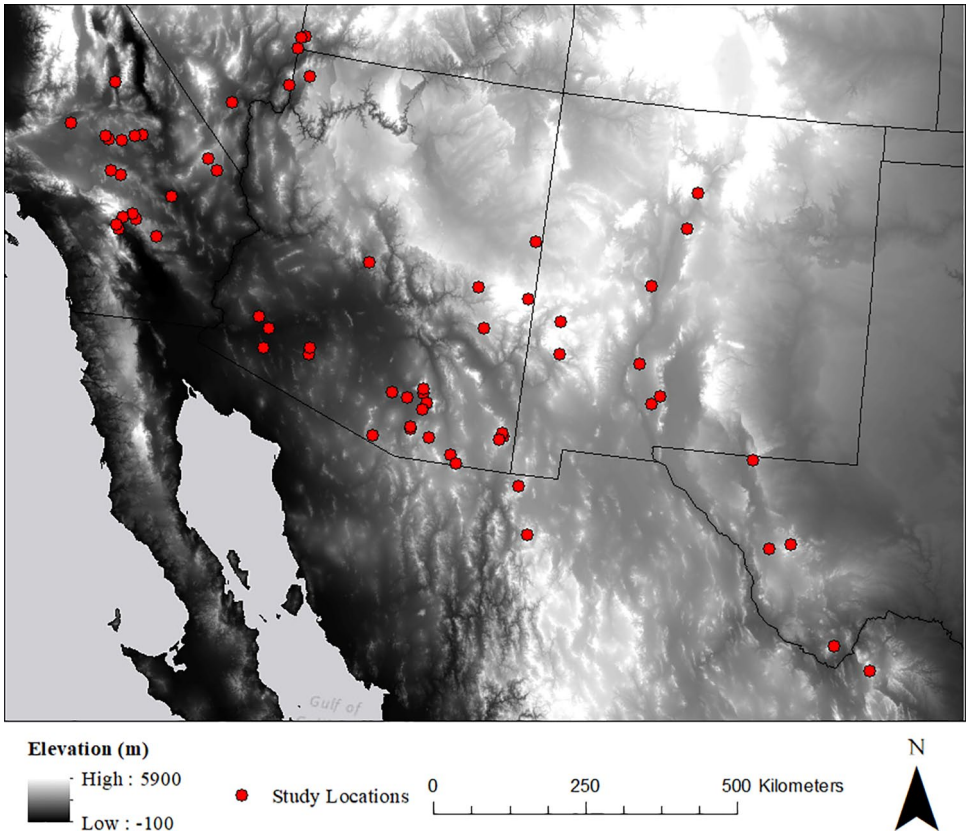


Figure 2. Locations of studies in ecosystems that occur along the US-Mexico border that address wildfire risk and fuel reduction treatments.

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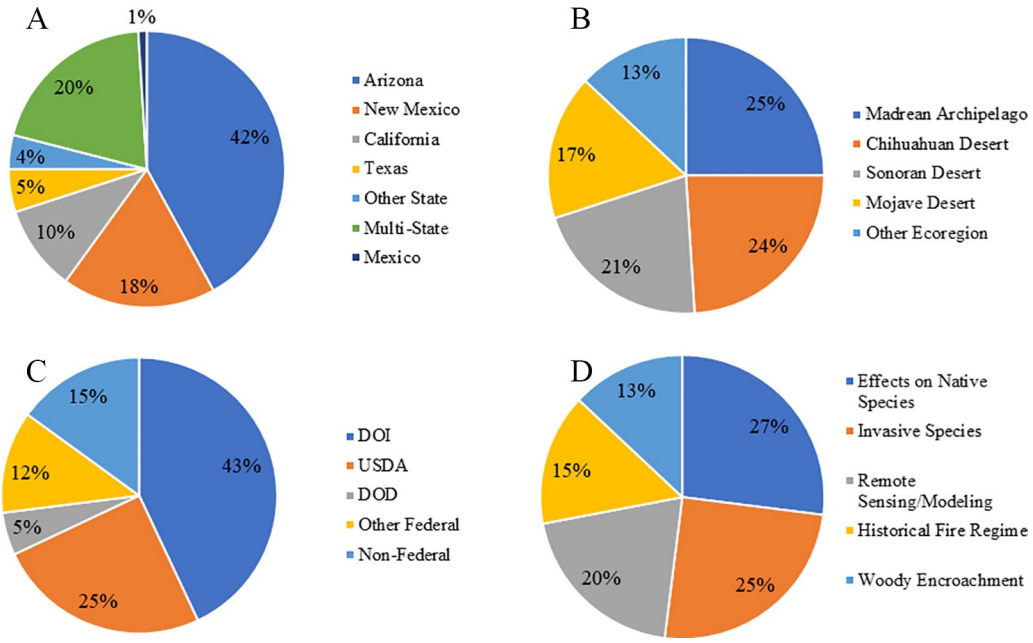


Figure 3. Studies that address wildfire risk and fuel reduction treatments along the US-Mexico border by (A) state and country, (B) ecoregion, (C) land ownership, and (D) topic.

species), 3% explored livestock grazing, and 20% considered multiple combinations of these treatments. Herbicide application was a secondary treatment examined in these studies but was not studied independently of other treatments. Studies that addressed both fuel treatments and wildfire risk could be divided into the primary topics of fire effects on native species (27%), invasive species (25%), woody encroachment (13%), historical fire regimes (15%), and remote sensing and modeling (20%) (Figure 3D).

Studies that addressed fire effects on native species found that fire can both increase[9] and decrease[10,11] the growth and productivity of native species. Several studies found mixed effects on plant species that depended on plant traits, fire characteristics, and pre-fire treatments.[12-17] Woody plants were often negatively affected by fire, whereas grasses and forb species often experienced post-fire increases in abundance.[13,18] However, rapid-reproducing woody species fared better following fire than poor recruiters,[15,16] and some perennial grasses that invested heavily in above ground compared with below ground production did not respond well to fire.[12] Negative responses to fire were further exacerbated by low soil nutrient[19] and water availability[20] conditions. Fire changed the spatial patterning of native vegetation[21] and leaf litter decomposition,[22] and enhanced soil erosion by decreasing native perennial vegetation cover.[23] Similar to the large variation in the responses of native plant species, native wildlife species had both positive and negative responses to fire.[10,24] Forest-dwelling species responded positively to fires that created intermediate heterogeneity in vegetation structure.[25,26] Importantly, preexisting fuel treatments including livestock grazing,[27] prescribed fire alone,[28] or prescribed fire in combination with mechanical treatments[20,29-33] reduced subsequent wildfire severity, associated declines in productivity and mortality of native species, and enhanced post-wildfire recovery.[30] Long-term fuel treatment effects on native species were assessed by Havstad and James,[34] who found that native vegetation cover was not influenced by prescribed fire 13 years after the burn treatment application, and by Strom and Fulé,[29] who projected that fuel treatments had multidecadal effects on native vegetation structure. These contrasting results can be explained by the recovery time of the species and ecosystems studied.

Studies on invasive species tended to focus on the grasses red brome (*Bromus rubens*) and schismus (*Schismus* spp.) in the Mojave Desert, buffelgrass (*Pennisetum ciliare*) in the Sonoran Desert, and Lehmann lovegrass (*Eragrostis lehmanniana*) in the Sonoran and Chihuahuan deserts. Studies on these non-native flammable species found that fire promoted their spread, leading to increased fire frequency and thereby supporting a positive feedback loop between fire and the invasive species.[35-41] The change in invasive species following wildfire can depend on fire frequency and severity[39] and soil type.[42] Although some studies found that the cover of invasive species did not increase after fire,[42-44] all studies generally agreed that invasive species increased wildfire risk.[45-52] Some of the factors these papers discussed as leading to the propagation of invasive species, and therefore the rise of wildfire risk, included high precipitation[42,43,51,52] and high soil nitrogen.[48,51] Fuel treatments caused a reduction,[49,53] as well as no changes to invasive species abundance.[42,43,47,54,55]

Similar to invasive species, woody plant species have increased in abundance along the US-Mexico border over the past several decades, including in areas previously occupied by grasslands.[56,57] Woody plant encroachment can increase the risk of a high severity fire, and several studies addressed treatments to reverse this pattern and help restore a low-severity fire regime. These studies found reduced woody plant abundance

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following prescribed burns in most cases,[55,58-60] but woody regeneration and interactions with grass species were variable depending on the fire season, fire return interval, and the degree of livestock grazing.[21,34,61-63] Fire rather than livestock grazing may have a larger role in maintaining grass dominance in the border region, although the mechanisms behind the balance of woody plants and grasses remain controversial.[56] Reductions in woody plant cover had a positive effect on wildlife species requiring more open and grass-dominated habitat, but negative effects on wildlife species requiring a higher density of woody vegetation.[64] Despite strong effects on wildlife, many woody plant species including mesquite recovered quickly following treatments.[65]

Historical wildfire regimes have been the topic of multiple studies that typically assess wildfire frequency, size, and severity. Many of these studies examined the relationship between fire characteristics and topographic attributes,[66-69] or fire characteristics and climate—specifically how wildfire risk can increase after antecedent wet years that increase fuel loads, followed by dry fire years.[68,70-72] Historical fire regimes along the border interact with land-use and associated characteristics—including livestock grazing,[73-75] land ownership,[76] and the degree of remoteness and historical management practices.[2] Larger fires were found to historically occur within the United States compared with Mexico, likely due to higher levels of fire exclusion and resulting fuel buildup.[2]

Much of the research on the topic of remote sensing and modeling was conducted across different plant communities including desert scrub, woodland, and forest of the Madrean Archipelago. Many studies focused on fuel types and biomass to assess wildfire risk[77-84] or used spectral vegetation indices to measure impacts of previous fires.[83,85] In addition, remote sensing was commonly used with the goal of modeling the spread of invasive grasses because of their role in increasing wildfire risk.[3,86,87] Using environmental characteristics to predict wildfire likelihood and severity was an approach found in several studies using slope, elevation, and climate.[88-90]

Soil was not a major topic of border studies included in our review despite its inclusion in searches. However, the influence of soils on wildfire and the effect of wildfire on soils were secondarily addressed in the literature. Wildfire frequency was enhanced with increasing elevation and soil moisture[69] and in shallow and fine-textured soils compared with deep and coarse-textured soils.[89] Brooks,[45] Allred and Snyder,[9] and Ladwig et al[19] all found an increase in soil nitrogen after fire, which has been shown to cause higher growth of invasive plants, increasing the risk of potential fires.[37,46,48,51,91] Multiple studies documented that fire promotes the redistribution of sediment and soil nutrients from under woody plant canopies to areas between woody plants, which can promote increases in perennial grass cover and reductions in woody encroachment.[58-60,92] Fire increased soil bulk density, runoff, sediment yield, and channelization while reducing water infiltration in ecosystems along the US-Mexico border.[23,93] In addition to increased susceptibility to water erosion, post-fire soils were exposed to elevated wind erosion, which could be further amplified by land-use that reduces perennial vegetation.[94,95]

Knowledge Gaps and Future Research

Our review highlights the state of knowledge of wildfire and fuel treatments in ecosystems that occur along the US-Mexico border and reveals several knowledge gaps and avenues for future research. Although invasive grasses in the southwestern United States and northern Mexico typically increase wildfire risk, more work is needed to better link the effects of different invasive species, including research, on fire-related traits in invasive species compared with native species and how these traits interact with environmental conditions to influence wildfire risk. The suppression of invasive species and promotion of native species are now occurring at large spatial scales, yet we know little about how these efforts are influencing wildfire risk and ecosystem recovery across broad management units. The importance of climate effects on wildfire and related invasive species abundance, together with forecasts of increasing aridity along the US-Mexico border,[96] suggests a growing need for studies that project how future climate will influence wildfire and the associated spread of invasive species. While future warming is likely to extend the fire season length and increase fuel flammability,[4] previous research in the US-Mexico border region has revealed the importance of antecedent wet conditions in promoting fine fuel production necessary to increase wildfire activity.[72] Villarreal et al[97] report in this special collection that recent fires deviate from historical fire regimes for most ecosystems along the border, especially at extreme ends of bioclimatic gradients. These results point out the need to experimentally impose climate extremes through rainfall or temperature manipulation[98] in conjunction with fire to determine important interactions that affect ecosystem condition. Research will have added value for future decision-making if connections are made between past fire-environment relationships and how fires might respond to future conditions.

More recently occurring wildfires have been used to understand how historical fuel treatments have affected fire behavior, and this research avenue is likely to be increasingly helpful for fire mitigation as the frequency and severity of wildfires are expected to intensify.[3,4] Pairing post-fire ecosystem monitoring with measurements that took place in the same area before the wildfire occurred offers a promising method to understand recovery patterns and opportunities for management intervention. Most of the fuel treatment studies we reviewed examined changes to wildfire risk over relatively short periods of time, but long-term monitoring is necessary to assess how the risk profile changes through time and when treatments need to be repeated.[99] Studies that assess post-fire linkages between vegetation and wildlife are especially helpful to understand ecosystem-level effects, yet are not abundant in the literature. Prescribed burning was the primary fuel treatment found in this review, but studies on the potential for fuel breaks and

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different treatment combinations and frequencies could help determine other effective prevention measures.

The variable topography, soils, and vegetation of the US-Mexico border not only present unique challenges for understanding wildfire activity, but also present opportunities for studies that employ environmental gradients, cross-site comparisons, and networked experiments to expand our knowledge. Similarly, the patchwork of land-uses and ownership along the border creates incentive to further explore how these factors influence wildfire activity and invites new research that crosses jurisdictional boundaries, including across the international border. Indeed, Villarreal et al[2,97] emphasize the need for continued collaboration and shared data sets from both sides of the border to adequately learn from historical fire regimes and understand the potential of future changes. Connectivity of fuels and related fire hazards across the US-Mexico border makes collaborative resource management increasingly important to reduce the risk of transboundary wildfire transmission and to improve ecosystem health.[100,101]

Studies were less common on the Mexico side of the border where much of the land is privately or communally *(ejidos)* held, and government-sponsored fire suppression and fuel management strategies often exist alongside local traditional burning practices and communal fire management.[102] Intentional fuel treatments in the Mexican borderlands are uncommon, but recently Mexican state and federal government agencies, universities, and local communities have collaborated on prescribed burns along the border,[103] with the objectives of reducing fuels, studying treatment effectiveness, and providing training on fuel management. Within the United States, studies in this review were particularly lacking on Native American lands and in Texas (Figure 1). The increasing number of studies on wildfire risk and fuel treatments along the US-Mexico border signifies a growing body of knowledge to inform land management decision-making in the region. Continued studies along the border, particularly research that fills important knowledge gaps, will help protect ecosystems and human populations that are at risk of negative fire impacts and will expand the knowledge needed to prepare for future wildfire regimes.

Acknowledgements

This review was supported by the Department of the Interior Office of Wildland Fire and the USGS Ecosystems Mission Area. Any use of trade, product, or firm names in this paper is for descriptive purposes only and does not imply endorsement by the US Government.

Author Contributions

This review was conceived by SMM. KML performed the literature search. KML and SMM wrote the paper with contributions from MLV.

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REFERENCES

1. McPherson GR, Weltzin JF. *Disturbance and climate change in United States/Mexico borderland plant communities: A state-of-the-knowledge review*. USDA For Serv Rocky Mountain Res Stn Gen Tech Rep RMRS-GTR-50; 2000. https://www.fs.usda.gov/treesearch/pubs/28848
2. Villarreal ML, Haire SL, Iniguez JM, Cortés Montaño C, Poitras TB. Distant neighbors: recent wildfire patterns of the Madrean Sky Islands of southwestern United States and northwestern Mexico. *Fire Ecol*. 2019;15. doi:10.1186/s42408-018-0012-x.
3. Abatzoglou JT, Kolden CA. Climate change in Western US deserts: potential for increased wildfire and invasive annual grasses. *Rangel Ecol Manag*. 2011;64:471-478. doi:10.2111/REM-D-09-00151.1.
4. Westerling AL, Hidalgo HG, Cayan DR, Swetnam TW. Warming and earlier spring increase Western U.S. forest wildfire activity. *Science*. 2006;313:940-943. doi:10.1126/science.1128834.
5. Allen CD, Savage M, Falk DA, et al. Ecological restoration of Southwestern ponderosa pine ecosystems: a broad perspective. *Ecol Appl*. 2002;12:1418-1433. doi:10.1890/1051-0761(2002)012[1418.
6. Krammes SJ. *Effects of fire management of southwestern natural resources*. Gen Tech Rep RM-191; 1990. https://www.fs.fed.us/rm/pubs_rm/rm_gtr191.pdf
7. DOI OWF. Southern Border Fuels Management; 2020. https://www.doi.gov/wildlandfire/southern-border-fuels-management
8. Hajost SA. US–Mexico environmental cooperation: agreement between the United States of America and the United Mexican States on cooperation for the protection and improvement of the border area. *Environ Law*. 1984:1-3.
9. Allred BW, Snyder KA. Ecophysiological responses of Chihuahuan desert grasses to fire. *J Arid Environ*. 2008;72:1989-1996. doi:10.1016/j.jaridenv.2008.06.008.
10. Esque TC, Webb RH, Wallace CSA, van Riper C, McCreedy C, Smythe L. Desert fires fueled by native annual forbs: effects of fire on communities of plants and birds in the lower Sonoran Desert of Arizona. *Southwest Nat*. 2013;58:223-233. doi:10.1894/0038-4909-58.2.223.
11. Steers RJ, Allen EB. Fire effects on perennial vegetation in the western Colorado Desert, USA. *Fire Ecol*. 2011;7:59-74. doi:10.4996/fireecology.0703059.
12. Gosz RJ, Gosz JR. Species interactions on the biome transition zone in New Mexico: response of blue grama (Bouteloua gracilis) and black grama (Bouteloua eripoda) to fire and herbivory. *J Arid Environ*. 1996;34:101-114. doi:10.1006/jare.1996.0096.
13. Drewa PB, Havstad KM. Effects of fire, grazing, and the presence of shrubs on Chihuahuan desert grasslands. *J Arid Environ*. 2001;48:429-443. doi:10.1006/jare.2000.0769.
14. Shryock DF, DeFalco LA, Esque TC. Life-history traits predict perennial species response to fire in a desert ecosystem. *Ecol Evol*. 2014;4:3046-3059. doi:10.1002/ece3.1159.
15. Barton AM, Poulos HM. Pine vs. oaks revisited: conversion of Madrean pine-oak forest to oak shrubland after high-severity wildfire in the Sky Islands of Arizona. *For Ecol Manage*. 2018;414:28-40. doi:10.1016/j.foreco.2018.02.011
16. Barton AM, Poulos HM. Response of Arizona cypress (Hesperocyparis arizonica) to the Horseshoe Two Megafire in a south-eastern Arizona Sky Island mountain range. *Int J Wildl Fire*. 2019;28:62-69. doi:10.1071/WF18133.
17. Thomas KA, Jarchow CJ, Crawford JA. Survival of the endangered Pima pineapple cactus: does clearing before prescribed fire alter survival postfire? *Southwest Nat*. 2017;62:200-206. doi:10.1894/0038-4909-62.3.200.
18. Stromberg JC, Rychener TJ, Dixon MD. Return of fire to a free-flowing desert river: effects on vegetation. *Restor Ecol*. 2009;17:327-338. doi:10.1111/j.1526-100X.2007.00347.x.
19. Ladwig LM, Collins SL, Swann AL, Xia Y, Allen MF, Allen EB. Above- and belowground responses to nitrogen addition in a Chihuahuan Desert grassland. *Oecologia*. 2012;169:177-185. doi:10.1007/s00442-011-2173-z.
20. Shive KL, Kuenzi AM, Sieg CH, Fulé PZ. Pre-fire fuel reduction treatments influence plant communities and exotic species 9 years after a large wildfire. *Appl Veg Sci*. 2013;16:457-469. doi:10.1111/avsc.12015.
21. Fuentes-Ramirez A, Mudrak EL, Caragea PC, Holzapfel C, Moloney KA. Assessing the impact of fire on the spatial distribution of Larrea tridentata in the Sonoran Desert, USA. *Oecologia*. 2015;178:473-484. doi:10.1007/s00442-014-3214-1.
22. Throop HL, Abu Salem M, Whitford WG. Fire enhances litter decomposition and reduces vegetation cover influences on decomposition in a dry woodland. *Plant Ecol*. 2017;218:799-811. doi:10.1007/s11258-017-0730-1.
23. O'Dea ME, Guertin DP. Prescribed fire effects on erosion parameters in a perennial grassland. *J Range Manag*. 2003;56:27-32. doi:10.2307/4003877.
24. Gordon CE. Fire and cattle grazing on wintering sparrows in Arizona grasslands. *J Range Manag*. 2000;53:384-389. doi:10.2307/4003748.
25. Doumas SL, Koprowski JL. Effect of heterogeneity in burn severity on Mexican fox squirrels following the return of fire. *Int J Wildl Fire*. 2013;22:405-413. doi:10.1071/WF12046.

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26. Doumas SL, Koprowski JL. Return of fire as a restoration tool: long-term effects of burn severity on habitat use by Mexican Fox Squirrels. *Restor Ecol*. 2013;21:133-139. doi:10.1111/j.1526-100X.2012.00864.x.
27. Bruegger RA, Varelas LA, Howery LD, Torell LA, Stephenson MB, Bailey DW. Targeted grazing in southern Arizona: using cattle to reduce fine fuel loads. *Rangel Ecol Manag*. 2016;69:43-51. doi:10.1016/j.rama.2015.10.011.
28. Walker RB, Coop JD, Parks SA, Trader L. Fire regimes approaching historic norms reduce wildfire-facilitated conversion from forest to non-forest. *Ecosphere*. 2018;9:e02182. doi:10.1002/ecs2.2182.
29. Strom BA, Fulé PZ. Pre-wildfire fuel treatments affect long-term ponderosa pine forest dynamics. *Int J Wildl Fire*. 2007;16:128-138. doi:10.1071/WF06051.
30. Yocom Kent LL, Shive KL, Strom BA, et al. Interactions of fuel treatments, wildfire severity, and carbon dynamics in dry conifer forests. *For Ecol Manage*. 2015;349:66-72. doi:10.1016/j.foreco.2015.04.004.
31. Springer JD, Huffman DW, Stoddard MT, Sánchez Meador AJ, Waltz AEM. Plant community dynamics following hazardous fuel treatments and mega-wildfire in a warm-dry mixed-conifer forest of the USA. *For Ecol Manage*. 2018;429:278-286. doi:10.1016/j.foreco.2018.06.022.
32. Petrakis RE, Villarreal ML, Wu Z, Hetzler R, Middleton BR, Norman LM. Evaluating and monitoring forest fuel treatments using remote sensing applications in Arizona, U.S.A. *For Ecol Manage*. 2018;413:48-61. doi:10.1016/j.foreco.2018.01.036
33. Neary DG, Zieroth EJ. Forest bioenergy system to reduce the hazard of wildfires: white Mountains, Arizona. *Biomass Bioenerg*. 2007;31:638-645. doi:10.1016/j.biombioe.2007.06.028.
34. Havstad KM, James D. Prescribed burning to affect a state transition in a shrub-encroached desert grassland. *J Arid Environ*. 2010;74:1324-1328. doi:10.1016/j.jaridenv.2010.05.035.
35. Anable ME, McClaran MP, Ruyle GB. Spread of introduced Lehmann lovegrass Eragrostis lehmanniana Nees. in Southern Arizona, USA. *Biol Conserv*. 1992;61:181-188. doi:10.1016/0006-3207(92)91114-8.
36. Brooks ML. Effects of high fire frequency in creosote bush scrub vegetation of the Mojave Desert. *Int J Wildl Fire*. 2012;21:61-68. doi:10.1071/WF10140.
37. Fuentes-Ramirez A, Schafer JL, Mudrak EL, et al. Spatio-temporal impacts of fire on soil nutrient availability in Larrea tridentata shrublands of the Mojave Desert, USA. *Geoderma*. 2015;259-260:126-133. doi:10.1016/j.geoderma.2015.05.016.
38. Brown DE, Minnich RA. Fire and changes in creosote bush scrub of the western Sonoran Desert, California. *Am Midl Nat*. 1986;116:411-422. doi:10.2307/2425750.
39. Klinger R, Brooks M. Alternative pathways to landscape transformation: invasive grasses, burn severity and fire frequency in arid ecosystems. *J Ecol*. 2017;105:1521-1533. doi:10.1111/1365-2745.12863.
40. Underwood EC, Klinger RC, Brooks ML. Effects of invasive plants on fire regimes and postfire vegetation diversity in an arid ecosystem. *Ecol Evol*. 2019;9:12421-12435. doi:10.1002/ece3.5650.
41. Brooks ML, Chambers JC. Resistance to invasion and resilience to fire in desert shrublands of North America. *Rangel Ecol Manag*. 2011;64:431-438. doi:10.2111/REM-D-09-00165.1.
42. Geiger EL, McPherson GR. Response of semi-desert grasslands invaded by non-native grasses to altered disturbance regimes. *J Biogeogr*. 2005;32:895-902. doi:10.1111/j.1365-2699.2004.01235.x.
43. McDonald CJ, McPherson GR. Absence of a grass/fire cycle in a semiarid grassland: response to prescribed fire and grazing. *Rangel Ecol Manag*. 2011;64:384-393. doi:10.2111/REM-D-10-00036.1.
44. Brooks ML, Matchett JR. Plant community patterns in unburned and burned blackbrush (Coleogyne ramosissima Torr.) shrublands in the Mojave Desert. *West North Am Nat*. 2003;63:283-298.
45. Brooks ML. Peak fire temperatures and effects on annual plants in the Mojave Desert. *Ecol Appl*. 2002;12:1088-1102. doi:10.1890/1051-0761(2002)012[1088.
46. Brooks ML. Effects of increased soil nitrogen on the dominance of alien annual plants in the Mojave Desert. *J Appl Ecol*. 2003;40:344-353. doi:10.1046/j.1365-2664.2003.00789.x.
47. McGlone CM, Huenneke LF. The impact of a prescribed burn on introduced Lehmann lovegrass versus native vegetation in the northern Chihuahuan Desert. *J Arid Environ*. 2004;57:297-310. doi:10.1016/S0140-1963(03)00109-5.
48. Rao LE, Allen EB. Combined effects of precipitation and nitrogen deposition on native and invasive winter annual production in California deserts. *Oecologia*. 2010;162:1035-1046. doi:10.1007/s00442-009-1516-5.
49. McDonald CJ, McPherson GR. Creating hotter fires in the Sonoran Desert: buffelgrass produces copious fuels and high fire temperatures. *Fire Ecol*. 2013;9:26-39. doi:10.4996/fireecology.0902026.
50. Fuentes-Ramirez A, Veldman JW, Holzapfel C, Moloney KA. Spreaders, igniters, and burning shrubs: plant flammability explains novel fire dynamics in grass-invaded deserts. *Ecol Appl*. 2016;26:2311-2322. doi:10.1002/eap.1371.
51. Horn KJ, Bishop TBB, St. Clair SB. Precipitation timing and soil heterogeneity regulate the growth and seed production of the invasive grass red brome. *Biol Invasions*. 2017;19:1339-1350. doi:10.1007/s10530-016-1348-2.
52. Moloney KA, Mudrak EL, Fuentes-Ramirez A, Parag H, Schat M, Holzapfel C. Increased fire risk in Mojave and Sonoran shrublands due to exotic species and extreme rainfall events. *Ecosphere*. 2019;10:e02592. doi:10.1002/ecs2.2592.
53. Steers RJ, Allen EB. Post-fire control of invasive plants promotes native recovery in a burned desert shrubland. *Restor Ecol*. 2010;18:334-343. doi:10.1111/j.1526-100X.2009.00622.x.
54. McGlone CM. No long-term effects of prescribed fire on Lehmann Lovegrass (Eragrostis lehmanniana)–Invaded desert grassland. *Invasive Plant Sci Manag*. 2013;6:449-456. doi:10.1614/ipsm-d-12-00059.1.
55. Villarreal ML, Norman LM, Buckley S, Wallace CSA, Coe MA. Multi-index time series monitoring of drought and fire effects on desert grasslands. *Remote Sens Environ*. 2016;183:186-197. doi:10.1016/j.rse.2016.05.026.
56. Browning DM, Archer SR. Protection from livestock fails to deter shrub proliferation in a desert landscape with a history of heavy grazing. *Ecol Appl*. 2011;21:1629-1642. doi:10.1890/10-0542.1.
57. Enquist CAF, Gori DF. Application of an expert system approach for assessing grassland status in the U.S.- Mexico borderlands: implications for conservation and management. *Nat Areas J*. 2008;28:414-428. doi:10.3375/0885-8608(2008)28[414.
58. Sankey JB, Ravi S, Wallace CSA, Webb RH, Huxman TE. Quantifying soil surface change in degraded drylands: shrub encroachment and effects of fire and vegetation removal in a desert grassland. *J Geophys Res Biogeosciences*. 2012;117:1-11. doi:10.1029/2012JG002002.
59. Wang G, Li J, Ravi S, Dukes D, Gonzales HB, Sankey JB. Post-fire redistribution of soil carbon and nitrogen at a grassland–shrubland ecotone. *Ecosystems*. 2019;22:174-188. doi:10.1007/s10021-018-0260-2.
60. White CS, Pendleton RL, Pendleton BK. Response of two semiarid grasslands to a second fire application. *Rangel Ecol Manag*. 2006;59:98-106. doi:10.2111/04-153R2.1.
61. Drewa PB. Effects of fire season and intensity on Prosopis glandulosa Torr. Var. Glandulosa. *Int J Wildl Fire*. 2003;12:147-157. doi:10.1071/WF02021.
62. Kupfer JA, Miller JD. Wildfire effects and post-fire responses of an invasive mesquite population: the interactive importance of grazing and non-native herbaceous species invasion. *J Biogeogr*. 2005;32:453-466. doi:10.1111/j.1365-2699.2004.01217.x.
63. Lee Molinari R, Bishop TBB, Bekker MF, Kitchen SG, Allphin L, St Clair SB. Creosote growth rate and reproduction increase in postfire environments. *Ecol Evol*. 2019;9:12897-12905. doi:10.1002/ece3.5771.
64. Kirkpatrick C, DeStefano S, Mannan RW, Lloyd J. Trends in abundance of grassland birds following a spring prescribed burn in southern Arizona. *Southwest Nat*. 2002;47:282-292. doi:10.2307/3672916.
65. Killgore A, Jackson E, Whitford WG. Fire in Chihuahuan Desert grassland: short-term effects on vegetation, small mammal populations, and faunal pedoturbation. *J Arid Environ*. 2009;73:1029-1034. doi:10.1016/j.jaridenv.2009.04.016.
66. Poulos HM, Gatewood RG, Camp AE. Fire regimes of the piñon-juniper woodlands of Big Bend National Park and the Davis Mountains, west Texas, USA. *Can J Res*. 2009;39:1236-1246. doi:10.1139/X09-052.
67. Iniguez JM, Swetnam TW, Yool SR. Topography affected landscape fire history patterns in southern Arizona, USA. *For Ecol Manage*. 2008;256:295-303. doi:10.1016/j.foreco.2008.04.023.
68. Brooks ML, Matchett JR. Spatial and temporal patterns of wildfires in the Mojave Desert, 1980-2004. *J Arid Environ*. 2006;67:148-164. doi:10.1016/j.jaridenv.2006.09.027.
69. Barton AM. Gradient analysis of relationships among fire, environment, and vegetation in a southwestern USA mountain range. *Bull Torrey Bot Club*. 1994;121:251-265. doi:10.2307/2997180.
70. Parks SA, Dobrowski SZ, Panunto MH. What drives low-severity fire in the southwestern USA? *Forests*. 2018;9:1-14. doi:10.3390/f9040165.
71. Meunier J, Romme WH, Brown PM. Climate and land-use effects on wildfire in northern Mexico, 1650-2010. *For Ecol Manage*. 2014;325:49-59. doi:10.1016/j.foreco.2014.03.048.
72. Crimmins MA, Comrie AC. Interactions between antecedent climate and wildfire variability across south-eastern Arizona. *Int J Wildl Fire*. 2004;13:455-466. doi:10.1071/WF03064.
73. Sakulich J, Taylor AH. Fire regimes and forest structure in a sky island mixed conifer forest, Guadalupe Mountains National Park, Texas, USA. *For Ecol Manage*. 2007;241:62-73. doi:10.1016/j.foreco.2006.12.029.
74. Poulos HM, Villanueva Díaz J, Cerano Paredes J, Camp AE, Gatewood RG. Human influences on fire regimes and forest structure in the Chihuahuan Desert Borderlands. *For Ecol Manage*. 2013;298:1-11. doi:10.1016/j.foreco.2013.02.014.
75. Fulé PZ, Yocom LL, Montaño CC, Falk DA, Cerano J, Villanueva-Díaz J. Testing a pyroclimatic hypothesis on the Mexico-United States border. *Ecology*. 2012;93:1830-1840. doi:10.1890/11-1991.1.
76. Ager AA, Palaiologou P, Evers CR, Day MA, Barros AMG. Assessing transboundary wildfire exposure in the Southwestern United States. *Risk Anal*. 2018;38:2105-2127. doi:10.1111/risa.12999.

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77. Sesnie SE, Eagleston H, Johnson L, Yurcich E. In-situ and remote sensing platforms for mapping fine-fuels and fuel-types in Sonoran semi-desert grasslands. *Remote Sens*. 2018;10;1358. doi:10.3390/rs10091358.
78. Rao LE, Matchett JR, Brooks ML, Johnson RF, Minnich RA, Allen EB. Relationships between annual plant productivity, nitrogen deposition and fire size in low-elevation California desert scrub. *Int J Wildl Fire*. 2015;24:48-58. doi:10.1071/WF13152.
79. Gray ME, Dickson BG, Zachmann LJ. Modelling and mapping dynamic variability in large fire probability in the lower Sonoran Desert of south-western Arizona. *Int J Wildl Fire*. 2014;23:1108-1118. doi:10.1071/WF13115.
80. VanLinn PF, Nussear KE, Esque TC, Defalco LA, Inman RD, Abella SR. Estimating wildfire risk on a Mojave Desert landscape using remote sensing and field sampling. *Int J Wildl Fire*. 2013;22:770-779. doi:10.1071/WF12158.
81. Poulos HM. Mapping fuels in the Chihuahuan Desert borderlands using remote sensing, geographic information systems, and biophysical modeling. *Can J Res*. 2009;39:1917-1927. doi:10.1139/X09-100.
82. Ball BJ. Fuel moisture prediction in homogeneous fuels using GIS and neural networks. *AI Appl*. 1997;11:73-78.
83. Henry MC, Yool SR. Characterizing fire-related spatial patterns in the Arizona Sky Islands using Landsat TM data. *Photogramm Eng Remote Sensing*. 2002;68:1011-1019.
84. White JD, Gutzwiller KJ, Barrow WC, Randall LJ, Swint P. Modeling mechanisms of vegetation change due to fire in a semi-arid ecosystem. *Ecol Modell*. 2008;214:181-200. doi:10.1016/j.ecolmodel.2008.02.032.
85. White JD, Swint P. Fire effects in the northern Chihuahuan Desert derived from Landsat-5 Thematic Mapper spectral indices. *J Appl Remote Sens*. 2014;8:083667. doi:10.1117/1.jrs.8.083667.
86. Frid L, Holcombe T, Morisette JT, et al. Using state-and-transition modeling to account for imperfect detection in invasive species management. *Invasive Plant Sci Manag*. 2013;6:36-47. doi:10.1614/ipsm-d-11-00065.1.
87. Büyüktahtakin İE, Feng Z, Olsson AD, Frisvold G, Szidarovszky F. Invasive species control optimization as a dynamic spatial process: an application to buffelgrass (Pennisetum ciliare) in Arizona. *Invasive Plant Sci Manag*. 2014;7:132-146. doi:10.1614/ipsm-d-13-00057.1.
88. Gray ME, Dickson BG. A new model of landscape-scale fire connectivity applied to resource and fire management in the Sonoran Desert, USA. *Ecol Appl*. 2015;25:1099-1113. doi:10.1890/14-0367.1.
89. Levi MR, Bestelmeyer BT. Biophysical influences on the spatial distribution of fire in the desert grassland region of the southwestern USA. *Landsc Ecol*. 2016;31:2079-2095. doi:10.1007/s10980-016-0383-9.
90. Holden ZA, Morgan P, Evans JS. A predictive model of burn severity based on 20-year satellite-inferred burn severity data in a large southwestern US wilderness area. *For Ecol Manage*. 2009;258:2399-2406. doi:10.1016/j.foreco.2009.08.017.
91. Rao LE, Allen EB, Meixner T. Risk-based determination of critical nitrogen deposition loads for fire spread in southern California deserts. *Ecol Appl*. 2010;20:1320-1335. doi:10.1890/09-0398.1.
92. Wang G, Li J, Ravi S, Theiling BP, Sankey JB. Fire changes the spatial distribution and sources of soil organic carbon in a grassland-shrubland transition zone. *Plant Soil*. 2019;435:309-321. doi:10.1007/s11104-018-3895-z.
93. DeLong SB, Youberg AM, DeLong WM, Murphy BP. Post-wildfire landscape change and erosional processes from repeat terrestrial lidar in a steep headwater catchment, Chiricahua Mountains, Arizona, USA. *Geomorphology*. 2018;300:13-30. doi:10.1016/j.geomorph.2017.09.028.
94. Field JP, Breshears DD, Whicker JJ, Zou CB. Interactive effects of grazing and burning on wind- and water-driven sediment fluxes: rangeland management implications. *Ecol Appl*. 2011;21:22-32. doi:10.1890/09-2369.1.
95. Dukes D, Gonzales HB, Ravi S, et al. Quantifying postfire aeolian sediment transport using rare earth element tracers. *J Geophys Res Biogeosciences*. 2018;123:288-299. doi:10.1002/2017JG004284.
96. Cook BI, Ault TR, Smerdon JE. Unprecedented 21st century drought risk in the American Southwest and Central Plains. *Sci Adv*. 2015;1:e1400082. doi:10.1126/sciadv.1400082.
97. Villarreal ML, Iniguez JM, Flesch AD, et al. Contemporary fire regimes provide a critical perspective on restoration needs in the Mexico-US borderlands. *Air, Soil Water Res*. 2020;(In Press).
98. Munson SM, Bunting EL, Bradford JB, Butterfield BJ, Gremer JR. Plant production responses to precipitation differ along an elevation gradient and are enhanced under extremes. *Ecosystems*. 2019;22:699-708. doi:10.1007/s10021-018-0296-3.
99. Copeland SM, Munson SM, Pilliod DS, Welty JL, Bradford JB, Butterfield BJ. Long-term trends in restoration and associated land treatments in the southwestern United States. *Restor Ecol*. 2018;26:311-322. doi:10.1111/rec.12574.
100. Gottfried GJ, Allen LS, Warren PL, McDonald B, Bemis RJ, Edminster CB. Private-public collaboration to reintroduce fire into the changing ecosystems of the southwestern Borderlands Region. *Fire Ecol*. 2009;5:85-99. doi:10.4996/fireecology.0501085.
101. Schoon M, York A, Sullivan A, Baggio J. The emergence of an environmental governance network: the case of the Arizona borderlands. *Reg Environ Chang*. 2017;17:677-689. doi:10.1007/s10113-016-1060-x.
102. Rodríguez-Trejo DA, Martínez-Hernández PA, Ortiz-Contla H, Chavarría-Sánchez MR, Hernández-Santiago F. The present status of fire ecology, traditional use of fire, and fire management in Mexico and Central America. *Fire Ecol*. 2011;7:40-56. doi:10.4996/fireecology.0701040.
103. Pérez Salicrup DR, Ortíz Mendoza R, Garduño Mendoza E, et al. Coordinación institucional para la realización de quemas prescritas y quemas controladas en México. *Rev Mex Ciencias for*. 2018;9:252-270. doi:10.29298/rmcf.v9i49.169.

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