

A Mosaic of Land Tenure and Ownership Creates Challenges and Opportunities for Transboundary Conservation in the US-Mexico Borderlands

MIGUEL L. VILLARREAL¹, SANDRA L. HAIRE², JUAN CARLOS BRAVO³ AND LAURA M. NORMAN⁴

¹U.S. Geological Survey, Western Geographic Science Center, Menlo Park, California, USA,

²Haire Laboratory for Landscape Ecology, Belfast, Maine, USA,

³Wildlands Network Mexico Program, Hermosillo, Sonora, Mexico,

⁴U.S. Geological Survey, Western Geographic Science Center, Tucson, Arizona, USA

Email: mvillarreal@usgs.gov

ABSTRACT In the Madrean Sky Islands of western North America, a mixture of public and private land ownership and tenure creates a complex situation for collaborative efforts in conservation. In this case study, we describe the current ownership and management structures in the US-Mexico borderlands where social, political, and economic conditions create extreme pressures on the environment and challenges for conservation. On the United States side of the border, sky island mountain ranges are almost entirely publicly owned and managed by federal, state, and tribal organizations that manage and monitor species, habitats, and disturbances including fire. In contrast, public lands are scarce in the adjacent mountain ranges of Mexico, rather, a unique system of private parcels and communal lands makes up most of Mexico's Natural Protected Areas. Several of the Protected Area reserves in Mexico form a matrix that serves to connect scattered habitats for jaguars dispersing northward toward public and private reserves in the United States from their northernmost breeding areas in Mexico. Despite the administrative or jurisdictional boundaries superimposed upon the landscape, we identify two unifying management themes that encourage collaborative management of transboundary landscape processes and habitat connectivity: jaguar conservation and wildfire management. This case study promotes understanding of conservation challenges as they are perceived and managed in a diversity of settings across the US-Mexico borderlands. Ultimately, recognizing the unique and important contributions of people living and working under different systems of land ownership and tenure will open doors for partnerships in achieving common goals. Una versión en español de este artículo está disponible como descarga.

KEY MESSAGE

This case study demonstrates how a diversity of social, political, and economic forces in border regions can create unique pressures on wildlife habitat. Conservation of landscapes that host a wide range of land uses, jurisdictions, and competing for management goals can be challenging, especially when considering habitat needs of wide-ranging species. However, there are unique opportunities when vested groups of private land owners and public land managers, even across international borders, find common ground in conservation.

INTRODUCTION

In the arid borderlands of southern Arizona and New Mexico, the United States and northern Sonora and Chihuahua, Mexico, isolated mountain ranges rise from hot desert floors to high elevations where cool temperatures and ample rainfall support pine and mixed conifer forests. These mountain ranges, known as "Sky Islands," support a wide diversity of wildlife and plant communities. Mountain forests form the headwaters of the major rivers in the region, providing much-needed water to the desert and its inhabitants below.

Apart from the metropolitan areas of Tucson, Arizona (population 535,677), Nogales, Sonora (population 212,533), and Cananea, Sonora (population 31,560), most of the region is rural and sparsely populated. Agriculture, mining, and ranching provide livelihoods in rural areas of both countries. Recreation, eco-tourism, and hunting provide major economic stimuli for communities in both countries, especially those near protected areas [1, 2].

The protected areas of the Sky Islands also provide important habitat linkages for species migrating between Mexico and the United States [3]. Jaguar (*Panthera onca*), the only extant member of its genus native to North America, roam these islands, traveling back and forth across the border at the northernmost extent of their range [4]. Jaguars are considered as endangered in both the United States and Mexico, under the Endangered Species Act and the Norma Oficial Mexicana 059-SEMARNAT-2010, respectively. Their presence in Sonora and Chihuahua depends on patchworks of habitat that fall within private properties, communal lands, and a few remaining federal lands. Many of these lands face serious threats, including vegetation cover loss and fragmentation by development, overgrazing by livestock, predator control by ranchers, border control infrastructure (i.e., fences and walls), and changing climates and disturbance regimes. These threats, when coupled with the unique conservation challenges in a region with immensely varied cultures, land uses, and science and conservation resources, require new ways of thinking about private–public conservation partnerships, international collaborations, and science communication and outreach.

CASE EXAMINATION

Sky Island Mountain Ecology

The Madrean Archipelago is well-known as a global biodiversity hotspot [5, 6]. The plant and animal assemblages of this region can be described as a mash-up of the many diverse ecosystems of the adjacent regions: a mixture of montane species from the Sierra Madre Occidental to the south and the Mogollon Rim and the Rocky Mountains to the north, as well as influences from the Chihuahuan and Sonoran deserts on its east and west flanks. The complex topography and steep elevation of the Sky Islands condense a gradient of plant communities into a small area, including deserts, thornscrub, and grasslands at low elevation to oak woodlands, pine, and mixed conifer forests

at high elevations [7] (Figure 1). These Sky Island plant communities are home to an astounding number of mammal, amphibian, and bird species [5, 8, 9], and the region is known for world-class birding and wildlife viewing.

Social and Political Barriers to Ecological Connectivity

Cases of successful transboundary conservation and collaboration can be found across the globe [10]. Similar to the Sky Islands, many approaches must include consideration of people living and working in critical conservation areas and encourage participatory management of shared resources [11]. Clearly defined conservation goals and sustained communication between stakeholders have proven effective for species conservation even in transboundary areas with a history of armed conflict [12]. However, political instability or changes in international border policies can potentially complicate or derail conservation even between countries with a long history of cooperation [13].

Border walls have become a recent historical trend in response to perceived threats from international migration across the globe between countries with markedly different economic, political, and cultural systems [14, 15]. Although the effectiveness of border walls to prevent movement of migrants and asylum seekers is questioned [14], scientists have raised serious concerns regarding the consequences for biodiversity and regional persistence and movement of wildlife [15–17].

The US-Mexico international border crosses the Madrean ecoregion near its center (Figure 2). The physical barrier and associated infrastructure are known to have considerable impacts on wildlife habitat connectivity, transboundary hydrology, and soil erosion [17]. The barrier and its direct and indirect effects can have a range of influences (i.e., dissect, filter, eliminate, or complicate movement) on small and large mammals alike [18]. The border demarcates political boundaries where land management, land-use history, and land-use intensity, as well as other factors, can be strikingly different just a short distance away [19]. The resulting differences in habitat in the border region can complicate species migration [20], particularly for highly mobile species with a majority of their range in one country and a peripheral portion in another [21]. In addition to physical barriers, cultural and linguistic differences (i.e., communication of research results, lack of translated literature, and differences in academic disciplines) can influence perceptions about the ecology



FIGURE 1. Images of the Madrean region (clockwise from top): (1) snow covering a burned forest in the Santa Catalina Mountains north of Tucson, Arizona, (2) view from the Sierra San Jose in Sonora, (3) high elevation forests of the Bavispe reserve, Sonora, and (4) a physical barrier at the international border in the hills near Nogales, Sonora. Photos courtesy of Aaron Flesch and Miguel Villarreal.

and biogeography of certain species [22], further complicating transboundary environmental management and habitat conservation. To maintain and restore habitat and habitat connectivity in this region, binational cooperation is imperative.

Role of Protected Areas in Landscape Connectivity and Conservation

In this case study, we outline the importance of government-owned protected areas, government-managed protected areas, and voluntary private conservation land in providing habitat connectivity in the Sky Islands. We describe how governments, private land owners, and communal land owners work together to ameliorate some of the pressures occurring in this region. We discuss the potential for collaborative management of landscape-scale processes, such as wildfire, where hazards,

as well as ecological benefits, are not contained within political and jurisdictional boundaries.

Unifying Management Themes

JAGUAR CONSERVATION. Over the past two centuries, jaguars have been extirpated from more than half of their historic range in the Americas, which spans both continents from the United States Southwest in the north through Mexico and Central and South America (Figure 2). Not surprisingly, most of this loss occurred at the extreme northern and southern portions of its range [23]. Recent jaguar sightings in the United States have all been males, but historically they were reported to breed in this country; the last known female jaguar in the United States was shot in Arizona in 1963 [4]. Much of the conservation effort in the Sky Island region is focused on maintaining habitat and habitat connectivity: jaguars use many different habitats

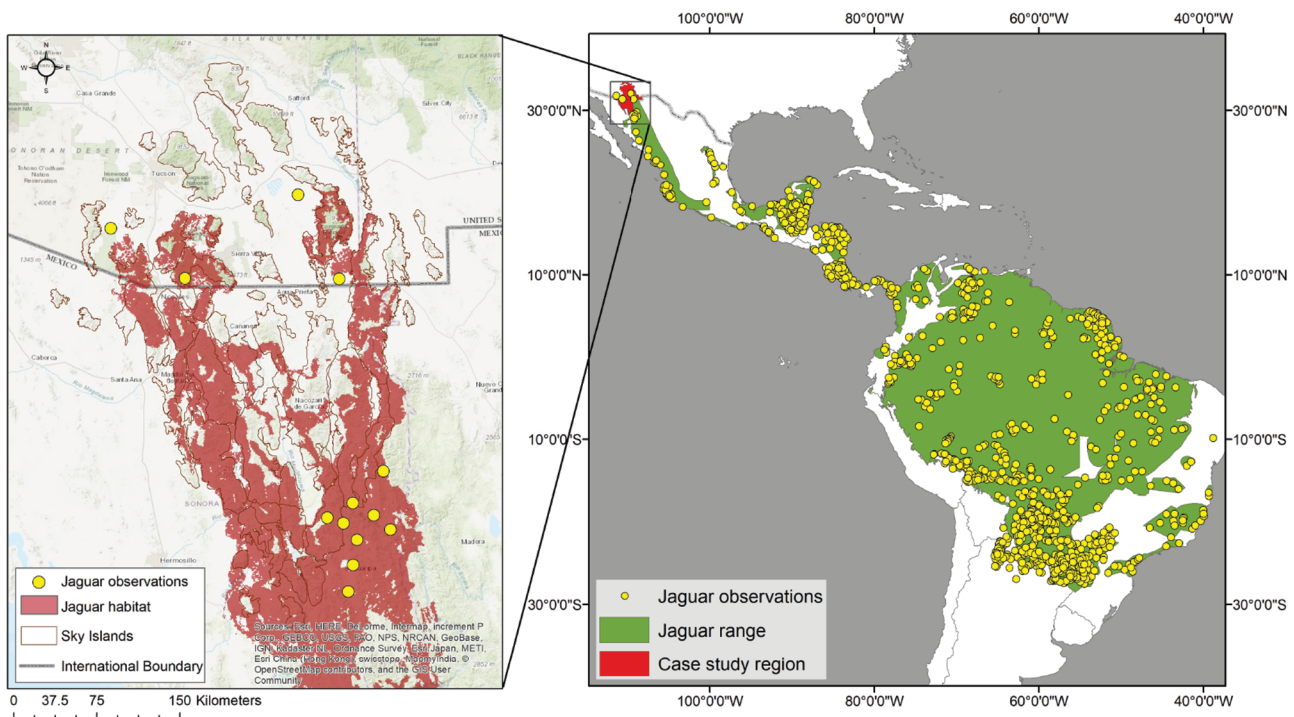


FIGURE 2. Maps showing modeled jaguar habitat connectivity in the Madrean ecoregion (left) and jaguar observations and range in North and South America (right). Jaguar habitat data courtesy [24] and observations [25, 26].

in the Sky Island region, but most of the sightings have been in Sinaloan thornscrub, Madrean oak woodlands, and pine-oak woodlands. Conservation of these jaguar habitats additionally serves hundreds of bird, mammal, and reptile species that make up much of the rich biodiversity of the region [8].

FIRE MANAGEMENT. Fire is a defining process for Sky Island forests and is necessary to maintain healthy and productive habitats for wildlife. Frequent low-moderate severity fires act to reduce dense woody biomass and create light and nutrient conditions needed to support the complex food webs wildlife depend on. Wildlife moves in response to both the immediate impacts of a fire event and the longer-term changes in plant communities that follow [27]. Effects of altered climate and fire patterns on animal movement can be detrimental to population health and persistence.

Humans have influenced fire regimes in the Sky Islands for centuries. Native Americans in the region used fire for multiple agricultural and ecological purposes [28] and some contemporary Tribal forest management programs continue to actively manage fire for ecological purposes [29]. In Mexico, many communities continue to make use of fire as well, harmonizing with food production and care

of the environment [30]. Extensive livestock grazing during the Anglo-American settlement of the southwestern United States followed by an effective policy of wildfire suppression contributed to altered fire regimes in many sky islands [31]. In Mexico, systematic fire suppression on public lands by the federal government never occurred to the extent it did on federally managed lands in the United States [32]. In both countries, non-native grasses introduced for livestock forage (e.g., *Eragrostis lehmanniana* and *Cenchrus ciliaris*) have outcompeted native plants and altered fire cycles [33]. Thus, legacies of land use, human-fire use, and fire suppression create variation in fire regimes across the region, as well as opportunities for landscape-scale management of fire and habitat in the face of changing climate and land-use pressures.

A MOSAIC OF LAND MANAGEMENT AND TENURE. In the United States, Federal agencies are primarily responsible for the management of natural resources of the sky islands. The Department of Agriculture's Forest Service manages the Coronado National Forest that includes 17 sky islands (>72,000 ha), including the Santa Rita and Chiricahua-Dos Cabeza mountains (Figure 3). These lands are managed for multiple uses, including mining, grazing, and recreation. US Department of the Interior

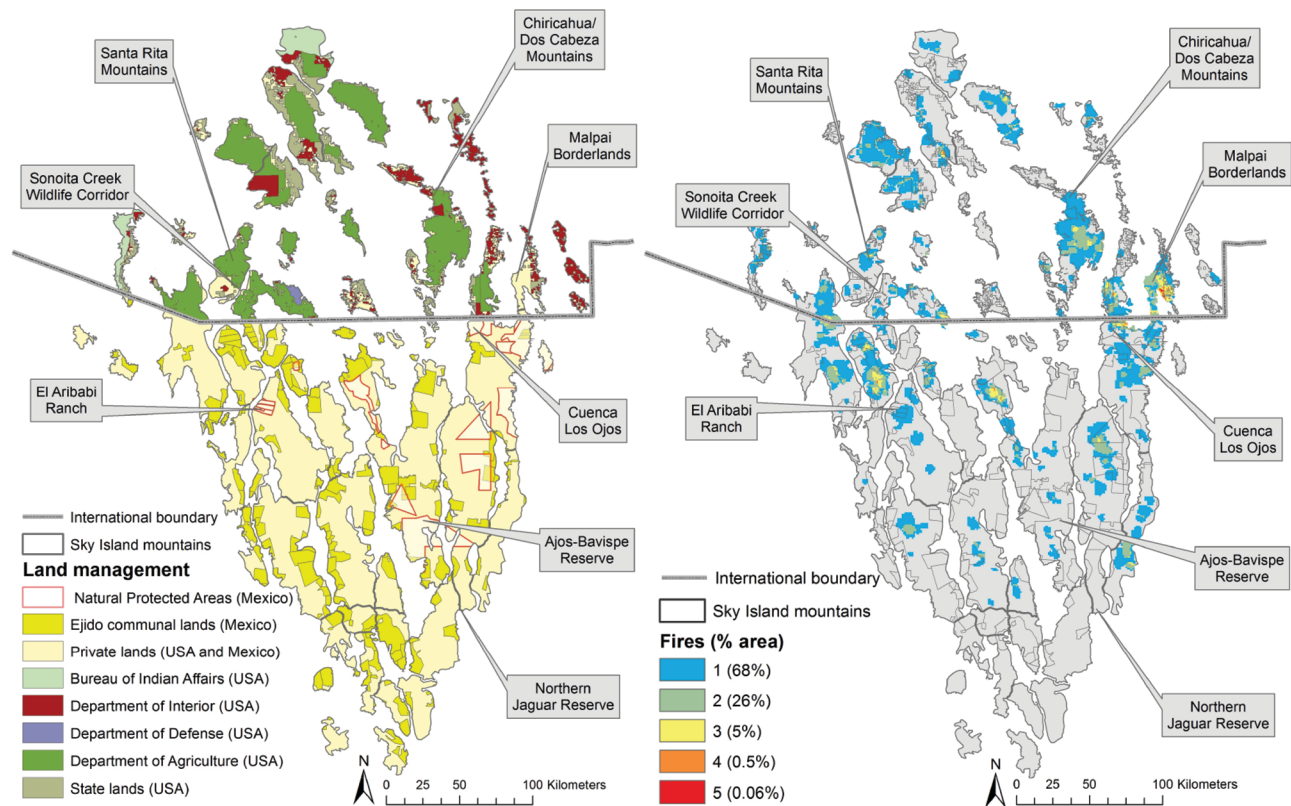


FIGURE 3. Map showing land tenure and management of the Sky Island mountain areas, and locations of some key conservation areas connecting the jaguar corridors (left) and wildfire location and frequency between 1985 and 2011 (right).

agencies manage some smaller protected areas in the sky islands, like National Parks, National Monuments, or Wilderness areas. National Park and Wilderness areas have a higher level of resource protections compared with the National Forests (e.g., no grazing or resource extraction). A few small, but important private reserves are scattered across the United States sky islands in the context of these federally managed lands, including the Malpai Borderlands and Sonoita Creek Wildlife Corridor (Figure 3).

While in the United States, several agencies govern conservation actions. In Mexico, it all starts and ends with the Secretariat of the Environment and National Resources (SEMARNAT). Through Commissions and Directorates, SEMARNAT executes conservation actions and regulates resource management throughout the country, implementing a vision focused on sustainable development and management of nature as a collection of resources for the common good, more than for the inherent values of wilderness. Natural Protected Areas [Áreas Naturales Protegidas (ANPs)] in Mexico are not public

lands, but represent a layer of regulation over a mosaic of tenures. The National Commission of Natural Protected Areas [Comisión Nacional de Áreas Naturales Protegidas (CONANP)], established in 2000, is a branch of SEMARNAT charged with implementing regulations to limit development and to promote, through incentives, wildlife conservation, and best practices among resource users within federally protected areas. Public lands are scarce in Mexico, so effective conservation, both inside and outside the limits of ANPs, must involve private parcels and communal lands known as *ejidos*. In turn, private lands, federal lands, and *ejidos* can voluntarily be certified as Areas Destined Voluntarily for Conservation (ADVC) within the National System of Protected Areas, such as Cuenca Los Ojos and El Aribabi Ranch in Sonora (Figure 3). Public reserves therefore constitute a designation of public interest across a mosaic of mostly private and communal lands.

CONNECTING CORE HABITAT THROUGH A NETWORK OF PUBLIC AND PRIVATE LANDS. Two protected areas are essential for preserving the core habitat for jaguar in the Sky

Islands. First, the Northern Jaguar Reserve (NJR) is located on the southern outskirts of the ecoregion where the sky islands transition from the Sierra Madre Occidental, an area considered the northernmost breeding habitat of jaguars in the continent (Figure 3). Beyond the NJR, jaguar movement to the north is presumed to occur along two main corridors, both of which pass through a second protected area, the Bavispe Natural Protected Area in Mexico (Figure 2), and then fork east and west across the border into the United States.

For this case study, we describe the core protected areas, including NJR and Bavispe, and protected areas that occur along the two corridors that connect with the northern reaches of the jaguar's range: (1) the Tumacácori Highlands to the west and (2) the Animas Valley to the east. We highlight some protected areas and public and private conservation groups who manage habitat within these corridors to promote persistence and movement of wildlife, representing a mix of conservation efforts. We provide a brief description of the geography, history, purpose, management, and the role of people in the core areas and east and west corridors.

Core Protected Areas

THE NORTHERN JAGUAR RESERVE. The 21,844 ha NJR (Figure 3) is a complex of properties in the municipality of Sahuaripa, Sonora, at the juncture of the Bavispe and Aros rivers, where they join to form the Yaqui, Sonora's most economically significant river and watershed. The area within and around the NJR is considered as the northernmost breeding area of jaguars in the continent. The Mexican conservation organization *Naturalia Comité para la Conservación de Especies Silvestres, A.C.* (*Naturalia*) purchased Los Pavos de Arriba y Pavos de Abajo, the first of several parcels in 2004 and, with the help of Northern Jaguar Project, continued purchasing properties adjacent to it over the next few years. In 2014, *Naturalia* sold or donated most of the properties to another Mexican organization named *Asociación Conservación del Norte A.C.* *Naturalia* has since obtained, through donations or purchases, two additional parcels adjacent to those owned by ACN. All of these properties are managed strictly for conservation with only one limited portion used for ranching by the reserve's cowboy and two parcels under temporary agreements to allow ranching by previous owners for a limited amount of time. No hunting is allowed in any of the properties.

BAVISPE AREA FOR THE PROTECTION OF FLORA AND FAUNA. North of NJR and scattered across three sky islands is the 200,914 ha Bavispe Natural Protected Area (Figure 3), Bavispe is made up of an assortment of federal, private, and communal lands all under federal protection. The Bavispe reserve is one of the oldest protected areas in Mexico, originally decreed by President Lázaro Cárdenas in 1936 as a "*portion of the land of the state of Sonora (the mountain ranges of Los Ajos, Buenos Aires and Púrica)*" and amended in 1939 to its current extent. Its original stated purposes were to provide services for local communities and industries: timber for industries such as mining; conserving and propagating vegetation to regulate hydrological and erosion processes; forestry by the local people; and conserving and attending to wildlife's proliferation. The 1936 and 1939 decrees refer to the lands being decreed as national lands (*terrenos nacionales*) and national forests (*bosques nacionales*), respectively, suggesting the lands were considered as public and federally owned. Currently, Sonora's Cadastral and Registry Institute (ICRESON) identifies all lands within Bavispe as either private or ejido lands. However, CONANP has managed to maintain effective control of all the lands within Sierra Los Ajos despite constant incursions and encroachment by ranchers, making it one of the few cases of federal conservation lands.

THE WESTERN CORRIDOR: TUMACÁCORI HIGHLANDS. The Tumacácori Highlands on the US-Mexico border north of Nogales is a hotspot for jaguar sightings in the United States [3]. The sky islands in Mexico that connect the NJR and Bavispe to the Tumacácori Highlands have no significant federal lands, and much of the conservation has been driven by private land owners and community-conservation organizations. One such example is Rancho El Aribabi (Figure 3). Located 35 miles south of the border, the 5-parcel complex of ADVCS (13,119 ha) lies at the bottleneck of jaguar, black bear, and ocelot corridor linking Mexico to the United States. El Aribabi has been owned by the same family since 1934, and in the last 15 years, the owners have attempted to support species conservation while maintaining traditional land uses, such as ranching and sustainable hunting. North of the border in Arizona, Borderlands Restoration LLC, a community-based ecological restoration group, purchased in 2015 a 400 ha parcel of land that was slated for housing developments (Figure 3). This land, known as the Sonoita Creek Wildlife Corridor, had been previously identified by

wildlife biologists as one of the key linkages in southern Arizona connecting jaguar, black bear, and puma habitats between sky islands in Mexico and Arizona [34]. The important parcel links the Huachuca Patagonia sky islands on the border to the Santa Rita mountains south of Tucson, where the jaguar known as “El Jefe” was sighted many times.

THE EASTERN CORRIDOR: ANIMAS VALLEY. To the east of the Tumacácori Highlands is the Animas Valley that connects the Bavispe and NRJ to the Chiricahua and Dos-Cabezas mountains, where the most recent US jaguar sighting occurred in 2018. Centered in the Animas Valley, the Malpai Borderlands Group (MBG; Figure 3) manages private ranches on a 300,000 ha area of land in both New Mexico and Arizona, much of it protected through conservation easements. MBG is a conservation-minded group of ranchers with a focus on using scientific information to drive resource management decisions [35]. The MBG model, based on cooperation between ranchers, researchers, and conservationists, illustrates how a flexible, grass-roots, and collaborative approach to conservation can be a successful alternative to management by a single entity.

Adjacent to the Malpai lands in Mexico is Cuenca Los Ojos (CLO), which consists of >40,000 ha of privately owned parcels in northeastern Sonora and northwestern Chihuahua, Mexico (Figure 3). Owners collaborate with different entities associated with Fundación Cuenca Los Ojos, a non-profit set up in Mexico by American conservationist Valer Clark. Restoration activities began at CLO in Sonora in 2001 with the removal of cattle as well as vegetation and watershed restoration [36].

Opportunities for Cross-Border Collaboration

CONSERVATION PARTNERSHIPS. Opportunities for collaborative conservation in the Sky Islands are currently being pursued by several regional organizations. The Sky Island Restoration Cooperative (SIRC) is a binational, community-based collaboration working toward effective landscape restoration (<https://skyislandalliance.org/what-we-do-programs/restore/sirc/>). SIRC facilitates restoration in both small scale, high priority habitats, and across entire watersheds, while expanding community involvement, volunteer opportunities, and economic development.

Wildlands Network (WN), a private international organization, is partnering with a coalition of conservation groups to spearhead habitat connectivity

projects in the Sky Islands (<https://wildlandsnetwork.org/campaigns/borderlands/>). The Borderlands Campaign priorities include conservation planning at Bavispe and consultation on the impacts of highway expansion on habitats and wildlife corridors at El Aribabi and Los Ojos. WN also collaborates in developing recommendations for United States federal management of key wildlife corridors and participates with scientists, communities, human rights organizations, and conservationists to oppose border barriers.

The Sonoran Joint Venture (SJV) is a partnership of diverse organizations and individuals from the southwestern United States and northwestern Mexico that works to develop cross-border partnerships to further the conservation of birds and their habitats. For example, the owners and managers at Rancho El Aribabi worked with SJV to explore ways to bring birders and others with an interest in natural history and diversify income from the ranch. The ranch now has accommodations for overnight guests for birding and natural history trips, meetings, and workshops (<https://elaribabi.com/ecotourism-habitat-protection-and-community-based-conservation-in-northwestern-mexico/>).

For people living and working within protected areas, managing wildfire is recognized as a way to meet multiple goals. The Bavispe Natural Protected Area is implementing fire management techniques that will help to maintain the ecological benefits of a frequent low-severity fire regime. In the Malpai Borderlands, managers are well-known for their pioneering use of fire for fuels and range management across multiple land ownership units [37]. In that same area, the Chiricahua-Dos Cabezas FireScape Project was implemented with multiple objectives, including the restoration of fire as a natural process across more than 200,000 ha of grasslands, woodlands, and forests (<https://azfirescape.org/chiricahua-dragoons-dos-cabezas>).

OUTREACH AND COMMUNICATION. The Madrean Archipelago conference series brings together researchers, students, managers, and conservation practitioners from both nations to share research and conservation efforts and to participate in training and workshops. The conferences, held in 1994, 2004, 2012, and 2018, are organized by a diverse committee representing universities, federal agencies, and private conservation organizations, such as the Sky Island Alliance (www.skyislandalliance.org) and The Nature Conservancy (www.nature.org). Proceedings from each conference have been published by the U.S. Forest Service Rocky Mountain Research Station.

BUILDING RESEARCH CAPACITY. The Next Generation of Sonoran Desert Researchers (N-Gen; <http://nextgensd.com>) fosters international research collaboration and communication by connecting organizations and individual researchers working across disciplines. Regional datasets are also opening up new possibilities for collaborative research and decision-making. For example, recently available fire history data from remote sensing fills a significant information gap [38]. These data are currently being used to examine the role of climate and human influence on landscape change. The synthesis of fire history data with field observations on plant and wildlife communities will be important in developing conservation and management decisions that incorporate fire as a keystone process.

CONCLUSIONS

Efforts by regional and local organizations to connect habitats, learn collectively, and collaborate on the management of landscape processes are in motion, despite the complexities of land ownership and tenure across the region. Exchanges of knowledge and technical expertise in collaborative settings hold potential for enabling implementation of effective conservation action [39], and transboundary networks of protected areas can improve the capacity for adaptation to rapidly changing climate conditions [40]. Ultimately, recognizing the unique and important contributions of people living and working under different systems of land ownership and tenure will open doors for partnerships in achieving common goals.

CASE STUDY QUESTIONS

1. What opportunities might exist to work collaboratively across international borders to conserve wide-ranging, migratory, and dispersing wildlife populations?
2. How can fire be used as a habitat management and conservation tool, given its traditional uses in the region, as well as potential conflicts with people in residence?
3. What are some potential challenges or pitfalls for maintaining an effective network of private and public conservation partnerships in an international setting like the US-Mexico borderlands?

4. This case study presents two “unifying management themes” that require collaborative conservation across large landscapes. What are some other cultural or natural resource management themes that might also encourage transboundary landscape conservation?
5. Given expected changes in climate, how can the network of protected areas function as stepping stones for regional species movement across climatic zones and mountain and desert ecosystems?

AUTHOR CONTRIBUTIONS

MV, SH, JB, and LN wrote the paper.

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SUPPORTING INFORMATION

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COMPETING INTERESTS

The authors declare that they have no competing interests.

REFERENCES

1. Cullinane TC, Koontz L, Cornachione E. 2017 national park visitor spending effects: Economic contributions to local communities, states, and the nation. Natural Resource Report NPS/NRSS/EQD/NRR—2018/1616. Fort Collins, Colorado: National Park Service; 2018.
2. Valdez R, Guzmán-Aranda JC, Abarca FJ, Tarango-Arámula LA, Sánchez FC. Wildlife conservation and management in Mexico. *Wildl Soc Bull.* 2006;34: 270–282.

3. Grigione MM, Menke K, López-González C et al. Identifying potential conservation areas for felids in the USA and Mexico: integrating reliable knowledge across an international border. *Oryx*. 2009;43(1): 78–86.
4. Brown DE, González CAL. Notes on the occurrences of jaguars in Arizona and New Mexico. *Southwestern Nat*. 2000;45(4): 537–542. doi:10.2307/3672607.
5. Felger RS, Wilson MF. Northern Sierra Madre Occidental and its Apachian outliers. In L. F. DeBano, P. H. Ffolliott, A. Ortega-Rubio, G. J. Gottfried, H. Hamre, & C. B. Edminster (Eds.), *Biodiversity and Management of the Madrean Archipelago: The Sky Islands of Southwestern United States and Northwestern Mexico* (pp. 36–59). Ft. Collins, CO: U.S. Forest Service.
6. Spector S. Biogeographic crossroads as priority areas for biodiversity conservation. *Conserv Biol*. 2002;16(6): 1480–1487.
7. Brown DE, Lowe CH, Pase CP. A digitized classification system for the biotic communities of North America, with community (series) and association examples for the Southwest. *J Arizona-Nevada Acad Sci*. 1979;14(1): 1–6.
8. Villarreal ML, Norman LM, Boykin KG, Wallace CS. Biodiversity losses and conservation trade-offs: assessing future urban growth scenarios for a North American trade corridor. *Int J Biodivers Sci Ecosyst Serv Manage*. 2013;9(2): 90–103.
9. Flesch, A.D. Patterns and drivers of long-term changes in breeding bird communities in a global biodiversity hotspot in Mexico. *Diversity and Distributions* 2019, 25, 499–513.
10. Kark S, Tulloch A, Gordon A, Mazor T, Bunnefeld N, Levin N. Cross-boundary collaboration: key to the conservation puzzle. *Curr Opin Environ Sustainability*. 2015;12: 12–24.
11. Sepúlveda B, Guyot S. Escaping the border, debordering the nature: protected areas, participatory management, and environmental security in Northern Patagonia (ie Chile and Argentina). *Globalizations*. 2016;13(6): 767–786.
12. Plumptre AJ, Kujirakwinja D, Treves A, Owijunji I, Rainer H. Transboundary conservation in the greater Virunga landscape: its importance for landscape species. *Biol Conserv*. 2007;134(2): 279–287.
13. Tanner R, Freimund W, Hayden B, Dolan B. *The Waterton-Glacier International Peace Park: Conservation Amid Border Security*. Peace Parks: Conservation and Conflict Resolution. Cambridge, Massachusetts, USA: MIT; 2007.
14. Jones R. *Borders and Walls: Do Barriers Deter Unauthorized Migration?*, Migration Information Source. The Online Journal of the Migration Policy Institute; 2016. Available: <https://www.migrationpolicy.org/article/borders-and-walls-do-barriers-deter-unauthorized-migration>.
15. Trouwborst A, Fleurke F, Dubrulle J. Border fences and their impacts on large carnivores, large herbivores and biodiversity: an international wildlife law perspective. *Rev Eur Comp Int Environ Law*. 2016;25(3): 291–306.
16. Flesch AD, Epps CW, Cain JW III, Clark M, Krausman PR, Morgart JR. Potential effects of the United States-Mexico border fence on wildlife. *Conserv Biol*. 2010;24(1): 171–181.
17. Peters R, Ripple WJ, Wolf C et al. Nature divided, scientists united: US-Mexico border wall threatens biodiversity and binational conservation. *Bioscience*. 2018;68(10): 740–743.
18. McCallum JW, Rowcliffe JM, Cuthill IC. Conservation on international boundaries: the impact of security barriers on selected terrestrial mammals in four protected areas in Arizona, USA. *PLoS One*. 2014;9(4): e93679.
19. Norman LM, Feller M, Guertin DP. Forecasting urban growth across the United States–Mexico border. *Comput Environ Urban Syst*. 2009;33(2): 150–159.
20. Dallimer M, Strange N. Why socio-political borders and boundaries matter in conservation. *Trends Ecol Evol*. 2015;30(3): 132–139.
21. Thornton DH, Wirsing AJ, Lopez-Gonzalez C et al. Asymmetric cross-border protection of peripheral transboundary species. *Conserv Lett*. 2018;11(3): 1–9.
22. List R, Ceballos G, Curtin C, Gogan PJ, Pacheco J, Truett J. Historic distribution and challenges to bison recovery in the northern Chihuahuan desert. *Conserv Biol*. 2007;21(6): 1487–1494.
23. Sanderson EW, Redford KH, Chetkiewicz CL et al. Planning to save a species: the jaguar as a model. *Conserv Biol*. 2002;16(1): 58–72.
24. Stoner KJ, Hardy AR, Fisher K, Sanderson EW. Jaguar habitat connectivity and identification of potential road mitigation locations in the Northwestern Recovery Unit for the Jaguar. Wildlife Conservation Society final draft report to the U.S. Fish and Wildlife Service in response to Solicitation F14PX00340, submitted 16 March 2015. pp. 29.
25. Marieb K. *Jaguars in the New Millennium Data Set Update*. WCS Working Paper. New York: Wildlife Conservation Society; 2006. pp. 1–80.
26. Zeller K. *Jaguars in the New Millennium Data Set Update: The State of the Jaguar in 2006*. WCS Report. New York: Wildlife Conservation Society; 2007. pp. 1–82.
27. Nimmo DG, Avitabile S, Banks SC et al. Animal movements in fire-prone landscapes. *Biol Rev*. 2018. Available: <https://doi.org/10.1111/brv.12486>.
28. Raish C, González-Cabán A, Condie CJ. The importance of traditional fire use and management practices for contemporary land managers in the American Southwest. *Global Environ Change Part B: Environ Hazards*. 2005;6(2): 115–122.
29. Petrakis RE, Villarreal ML, Wu Z, Hetzler R, Middleton BR, Norman LM. Evaluating and monitoring forest fuel treatments using remote sensing applications in Arizona, USA. *For Ecol Manage*. 2018;413: 48–61.
30. 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(1): 40–56.

31. Swetnam TW, Baisan CH. Fire Histories of Montane forests in the Madrean Borderlands. In: Ffolliott PF, DeBano LF, Maker MB, Gottfried GJ, Solis-Garza G, Edminster CB, et al., editors. Proceedings of a Symposium: Effects of Fire on Madrean Province Ecosystems. Fort Collins, Colorado, USA: USDA Forest Service General Technical Report RM-GTR-289, Rocky Mountain Research Station; 1996. pp. 15–36.
32. Villarreal ML, Yool SR. Analysis of fire-related vegetation patterns in the Huachuca Mountains, Arizona, USA, and Sierra los Ajos, Sonora, Mexico. *Fire Ecol.* 2008;4(1): 14.
33. Anable ME, McClaran MP, Ruyle GB. Spread of introduced Lehmann lovegrass *Eragrostis lehmanniana* Nees. in southern Arizona, USA. *Biol Conserv.* 1992;61(3): 181–188.
34. Beier P, Garding E, Majka D. Arizona Missing Linkages: Patagonia – Santa Rita Linkage Design. Report to Arizona Game and Fish Department. School of Forestry, Northern Arizona University; 2008. Available: http://corridor-design.org/dl/linkages/reports/Patagonia-SantaRita_LinkageDesign.pdf.
35. Curtin CG. Integration of science and community-based conservation in the Mexico/US borderlands. *Conserv Biol.* 2002;16(4): 880–886.
36. Norman L, Villarreal M, Pulliam HR et al. Remote sensing analysis of riparian vegetation response to desert marsh restoration in the Mexican Highlands. *Ecol Eng.* 2014;70: 241–254.
37. 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(1): 85–99.
38. Villarreal ML, Haire SL, Iniguez JM, Montaña CC, Poitras TB. Distant neighbors: recent wildfire patterns of the Madrean Sky Islands of southwestern United States and northwestern Mexico. *Fire Ecol.* 2019;15(1): 2.
39. Wolf S, Keitt B, Aguirre-Muñoz A, Tershy B, Palacios E, Croll D. Transboundary seabird conservation in an important North American marine ecoregion. *Environ Conserv.* 2006;33(4): 294–305.
40. Monahan WB, Theobald DM. Climate change adaptation benefits of potential conservation partnerships. *PLoS One.* 2018;13(2): e0191468.