Desert Landscape Conservation Center

Transboundary Madrean Watersheds Landscape Conservation Design Report

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Executive Summary

Landscape Conservation Cooperatives and Conservation Designs

Conservation issues such as climate change, shifts in water availability, wildfires, and development are occurring at larger extents than that of individual management areas. Large-landscape collaboration and planning that results in a Landscape Conservation Design (LCD) is one way to address these issues at a scale that is relevant to ecological process. A network Landscape Conservation Cooperatives was established by the U.S. Department of Interior in 2010 to build large-landscape conservation by facilitating collaboration across jurisdictional boundaries, developing shared conservation priorities and science needs, and creating strategies to be implemented through partnerships. The Transboundary Madrean Watersheds Landscape Conservation Design, which includes the Madrean Conservation Blueprint, is the result of a multi-year collaborative effort led by the Desert Landscape Conservation Cooperative, now known as the Desert Landscape Conservation Center (Desert LCC).

LCD provides information, analytical tools, and spatially explicit data to develop shared conservation strategies and to achieve conservation goals jointly held among partners. An LCD includes the following elements: a) convening partners; b) assessing current and future ecosystem conditions; c) vulnerability assessments and scenarios; d) spatial design components including priority resources, connectivity, biodiversity, human well-being, and ecosystem services; and e) strategy design (LCC Network 2018). Because the Desert LCC geography covers 186 million hectares (460 million acres), three pilot areas were chosen in which to develop LCDs first - the Dos Rios region, the Transboundary Madrean Watersheds region, and the Eastern Mojave region. The Transboundary Madrean Watersheds area as defined for the purpose of this LCD, encompasses approximately 22.7 million hectares (56.1 million acres) and over 65 individual Sky Island mountains in the U.S. and Mexico that reach up to 3,000 meters (10,000 feet) in elevation and support the most biodiverse oak and pine communities in North America (Warshall 1995).

Madrean Landscape Conservation Design Approach

The Transboundary Madrean Watersheds area spans the states of Arizona, New Mexico, Sonora, and Chihuahua in the U.S. and Mexico and is characterized by isolated forested mountains "sky islands" surrounded by a "sea" of intervening grasslands and deserts. It covers approximately 22.7 million hectares (56.1 million acres) and land ownership is a patchwork of protected and unprotected public and private lands. A broad spectrum of partners – federal, state and local government agencies; tribal sovereign nations, non-government organizations and academia; private sector interests and the public – are working together here with the shared vision to maintain and enhance the interconnected system of mountains, grasslands, deserts, and waters that supports species diversity, promotes healthy watersheds, and maintains the overall ecosystem integrity that enriches the lives of human communities. No single organization or entity can achieve this vision, so we undertook a structured collaborative effort – the Madrean

Landscape Conservation design to identify valued resources and ecosystem services, consider stressors and threats, and align and connect efforts.

The Madrean LCD and Conservation Blueprint described herein uses a portfolio of indicators to assesses spatial and temporal patterns, vulnerabilities, risks, and opportunities for valued resources; results in a set of spatially explicit products and adaptation strategies; and ensures biodiversity, ecosystem services, and social-ecological systems are resilient and sustainable for future generations. The Blueprint provides a common agenda and a framework to help individual partners from local governments to statewide and regional management agencies undertake actions that fulfill their individual conservation and management goals while also supporting priorities shared by the large group.

We chose several units of analysis in order to address conservation goals and management challenges that present at different scales. Analysis of indicators by HUC12 watersheds (a small geographic unit bound by topographic and hydrological influence) provide information across the large-landscape but at a scale that will be relevant to decisions about where to locate conservation and restoration projects. Analysis of indicators within mountain and grassland cores provide information about undeveloped blocks of ecosystems that are important for conserving biological diversity. Analysis of indicators within wildlife linkages provides information about conserving connectivity across the landscape. In addition, the exercise of selecting indicators and spatially analyzing them provide a wealth of information about science and monitoring needs across the Madrean landscape.

The Madrean Conservation Blueprint is the central visual, decision-support feature of the Madrean LCD and consists of maps delineating ecosystems and how best to conserve and restore them. There are dozens of additional products developed over years of collaborative planning that are useful in their own right. Table 1 describes the reports, online tools, webinars and other products that can be accessed to inform conservation work in the Madrean Transboundary Watersheds.

Table 1. Madrean LCD information products.

Name	Format	Location to access
Collaborative Conservation and Adaptation Strategy Toolbox (CCAST)	Online Library	Website
Transboundary Madrean Watersheds - Management Challenges and Actions	Webinar	Youtube
Transboundary Madrean Watershed Pilot Area Workshop - Panel Discussion	Webinar	Youtube
Springs Tool Viewer 1.0	Online Map	SkyIslandAlliance.org
Madrean Conservation Blueprint Map	Online Map	SkyIslandAlliance.org
Transboundary Madrean Watershed Pilot Area Workshop - Day 1	Webinar	Youtube
Transboundary Madrean Watershed Pre-workshop webinar	Webinar	Youtube
Landscape Conservation Design Transboundary Madrean Watersheds Pilot Area Kickoff webinar	Webinar	Youtube
Spatial Analysis Products and Indicators for the Madrean Watersheds LCD	Webinar	DesertLLC.org

Chapter 1—Introduction

Landscape Conservation Cooperatives and Conservation Design

Conservation issues such as climate change and shifts in water availability, wildfires, land-use patterns, and development are occurring at much larger extents than that of individual management areas (Comer et al. 2013; Dennison et al. 2014; Garfin et al. 2014). It is imperative to address these conservation issues at the large-landscape scale because they transcend jurisdictions and institutions (McKinney et al, 2010). Responding requires coordinated planning and action at a scale that is relevant to ecological and evolutionary process (Baldwin et al., 2018). A network of 22 Landscape Conservation Cooperatives was established by the U.S. Department of Interior in 2010 to build systematic large-landscape conservation by facilitating collaboration across jurisdictional boundaries, developing shared conservation priorities and science needs, and creating strategies to be implemented through partnerships. (National Academies of Sciences, Engineering, and Medicine, 2016).

The Desert Landscape Conservation Cooperative, now the Desert Landscape Conservation Center (Desert LCC), was launched by the Bureau of Reclamation and the U.S. Fish and Wildlife Service. It addressed landscape conservation in the southwestern United States and northern Mexico by bringing together managers, stakeholders, communities, and others to sustain resilient landscapes capable of responding to environmental challenges and supporting natural and cultural values for current and future generations (Mistzal et al. 2016).

In 2016, the Desert LCC began a landscape conservation design process. Landscape Conservation Design (LCD) provides information, analytical tools, and spatially explicit data to develop shared conservation strategies and to achieve conservation goals jointly held among partners (LCC Network 2018). A LCD indicates where conservation, and restoration actions may best contribute to sustaining ecological and social values and functions of the landscape. LCD differs from traditional sustainability planning in several key ways: it involves multiple institutions rather than a single institution; the focus is region-wide rather than within jurisdictional boundaries; the process is stakeholder-driven rather than institution-driven; and it guides collective action at the regional-scale rather than directing institutional action at site-specific scales (Campellone et al. 2018).

An LCD assesses spatial and temporal patterns, vulnerabilities, risks, and opportunities for landscape elements valued by stakeholders; results in a set of spatially explicit products and adaptation strategies; and ensures biodiversity, ecosystem services, and social-ecological systems are resilient and sustainable for future generations (Campellone et al. 2018). An LCD includes the following elements: a) convening partners; b) assessing current and future ecosystem conditions; c) vulnerability assessments and scenarios; d) spatial design components including priority resources, connectivity, biodiversity, human well-being, and ecosystem services; and e) strategy design (LCC Network 2018).

The Transboundary Madrean Watersheds Landscape Conservation Design (LCD) was developed as part of an effort initiated by the Desert Landscape Conservation Cooperative (Desert LCC). The Desert LCC was a program of the Bureau of Reclamation and the US Fish and Wildlife

Service to facilitate large-landscape conservation in the southwestern United States and northern Mexico. This collaborative effort brought together managers, stakeholders, communities, and others to work toward sustaining resilient landscapes capable of responding to environmental challenges and supporting natural and cultural values for current and future generations. The Desert LCC was charged with working in a very large area, covering over 450 million acres in portions of California, Arizona, New Mexico, Texas and a large part of northern Mexico. Due to the size of this landscape, smaller pilot areas with similar ecology were identified in which to develop tools and conservation plans with partners. The Transboundary Madrean Watersheds[1] is one of three such areas (Figure 1), selected from 13 nominations by the Desert LCC Steering Committee (see Appendix 1a for additional information on pilot area solicitation and selection).

Madrean Watersheds Geography

The Desert LCC geography covers 186 million hectares (460 million acres) and three pilot areas were chosen in which to develop LCDs first - the Dos Rios area, the Transboundary Madrean Watersheds area, and the Eastern Mojave area. The Madrean Watersheds sit at the heart of the Desert LCC geography and encompass some of the most rugged and remote landscapes in the American Southwest and is rich in biodiversity. The area spans the states of Arizona, New Mexico, Sonora, and Chihuahua. It is characterized by isolated forested mountains "sky islands" surrounded by a "sea" of intervening grasslands and deserts (Figure 2). The landownership is a patchwork of protected and unprotected public and private lands. In total it covers approximately 22.7 million hectares (56.1 million acres) and at least 55 individual Sky Island mountains in the U.S. and Mexico. Sky Islands reach up to 3,000 meters (10,000 feet) in elevation and support the most biodiverse pine-oak communities in North America (McLaughlin 1995; Warshall 1995).

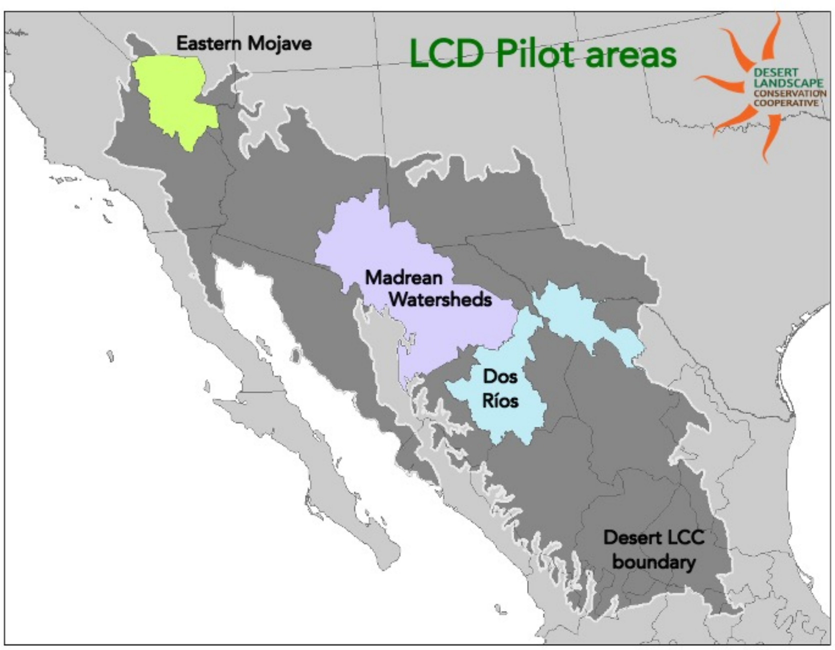

Figure 1. Landscape Conservation Design pilot areas in the Desert LCC.

[1] For simplicity this is referred to throughout as Madrean LCD

U.S. Climate projections for this area indicate it will undergo some of the greatest changes in temperature and water availability in North America over the next decades (Garfin et al. 2014; Williams et al. 2010). This unique landscape faces complex challenges into the future, including longer and more extreme droughts, spatial and temporal changes in precipitation, increased groundwater withdrawal, invasive species, changing fire regimes, and expanding human communities. This multitude of environmental and social factors are manifest on large scales that transcend jurisdictions and institutions. Addressing these challenges requires coordinated planning and action at the scale of these issues. Landscape Conservation Design is a tool to facilitate collaboration across jurisdictional boundaries, developing shared conservation priorities and science needs, and creating strategies to be implemented through partnerships.

The Desert LCC developed the Madrean LCD to achieve the following goals: 1) maximize the integrity of ecological systems that characterize natural areas and managed landscapes that people care about; 2) maximize structural and functional connectivity of the landscape for the movements of genes, propagules (pollen and seeds), individuals, and populations; and, 3) ensure the persistence of biological diversity of ecosystems and habitats, including the conservation of species diversity (Mistzal et al. 2017). To assess ecosystem condition and trends we assembled a portfolio of spatial indicators that are ecologically and socially relevant, useful to inform management and conservation goals, and can guide placement of conservation activities. The portfolio of indicators for the Madrean Watersheds is the basis for a series of spatial analyses that can assist partners in determining where conservation, restoration, and climate adaptation actions may have the most beneficial impact.

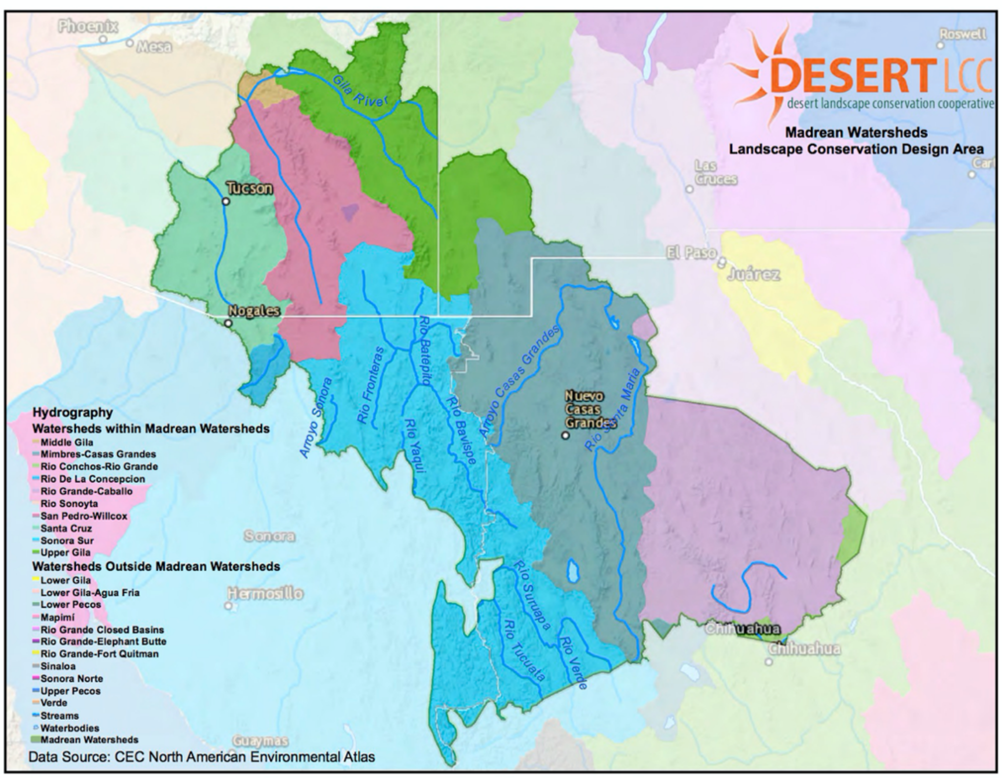

Figure 2. Transboundary Madrean Watersheds Landscape Conservation Design Area.

Process and Methods

Landscape Conservation Design involved the integration of societal values with ecological goals to describe where conservation can best be applied to support a resilient landscape. It was an iterative, collaborative, and holistic process to create strategic and spatial products that provide information, analytical tools, maps, and strategies to achieve landscape goals collectively held among partners (Desert Landscape Conservation Cooperative 2016). Partner-driven collaboration was foundational to the Madrean LCD process. From the outset, the effort was based on partner priorities and management realities, rather than top-down directives.

The LCD process included:

- Establishing a shared vision and goals.
- Gathering existing plans, projects and data.
- Identifying high-priority challenges and stressors.
- Discussing actions and strategies for supporting resilience in the face of a changing climate.
- Iteratively engaging partners in developing tools that support their efforts.

Partner input throughout the process helped to identify shared values and priorities across the landscape. These in turn formed the foundation of Madrean LCD components: priority ecosystems, key stressors, ecosystem integrity indicators, management strategies and science needs, and a map-based Conservation Blueprint 1.2 (https://skyislandalliance.org/madreanlcd/).

Planning began in late 2015 with gatherings of Desert LCC partners from agencies, organizations, and institutions of the United States and Mexico in a series of bi-national workshops in Tucson, Arizona; Aguascalientes, Mexico; and Alpine, Texas (Appendix 1b). Meetings were attended by over 140 participants from 45 different agencies and organizations. In this preliminary stage, partners worked to identify shared values, pressing challenges, and stressors across the landscape, as well as gathered relevant existing plans and information.

Figure 3. Madrean partners at May 2016 Workshop - Tucson, Arizona.

After laying this foundational work, the Madrean LCD effort was formally initiated with the *Madrean Partner Workshop* in Tucson, Arizona in 2016 (Figure 3; Appendix 1c). At this gathering, more than 90 partners developed shared goals and objectives, focal resources, key management questions, and identified information gaps. Participants also identified locally relevant management strategies that are or could be used to help achieve shared goals.

Following the *Madrean Partner Workshop*, the core team of Madrean LCD staff from Sky Island Alliance, the US Fish and Wildlife Service, and Southwest Decision Resources convened a Coordinating Team to provide ongoing guidance and input (Figure 4). The Coordinating Team focused on ensuring that outcomes of the LCD process were steeped in the realities of managing resources on the ground and relevant to sub-watersheds within the larger geography.

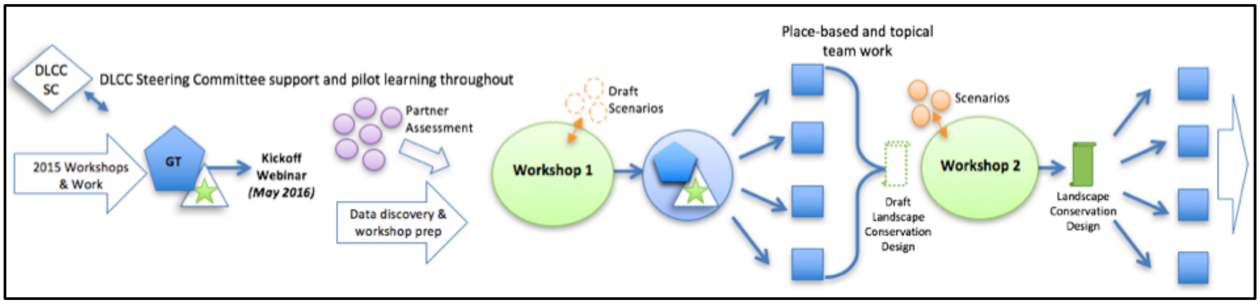

Figure 4. Madrean LCD Process Diagram.

The Coordinating Team comprised partners from agencies, organizations and research institutions across the region. This team's role was to provide overall guidance for the design and implementation of the process, and to help ensure the effort remained relevant to on-the-ground conservation and restoration actions.

In addition to the Coordinating Team, a wide and diverse group of partners and stakeholders were involved throughout the process. The Core Team maintained a partner contact list of over 250 individuals who received regular updates (see Appendix 1a), and participated as relevant in workshops, working groups and topic-specific meetings, such as the Indicator Development Workshop, November 2017 in Tucson (see Appendix 2a).

Organizations Participating in the Coordinating Team

Lower San Pedro Watershed Alliance

Southwest Climate Science Center

University of Arizona School of Renewable Natural Resources

Bureau of Reclamation

U.S. Fish and Wildlife Service

The Nature Conservancy

Pima County

U.S. Forest Service – Coronado National Forest

Wildlands Network

A land manager focus group in early 2017 helped to refine what types of tools and resources are most helpful to managers. In consultation with the Coordinating Team and participating partners, we developed indicators tied to the focal resources and management strategies. In November 2017, key partners came together to identify relevant indicators (see Chapter 2). These indicators became the basis for the development of spatial data products and the adaptation strategies toolbox (Appendix 2a). In addition, a community watershed forum in the Lower San Pedro watershed was convened in August 2017 as part of the Madrean LCD effort. This event was very well-received and spurred the creation of the Lower San Pedro Collaborative, which continues to meet and work on key resource issues and challenges in that landscape.

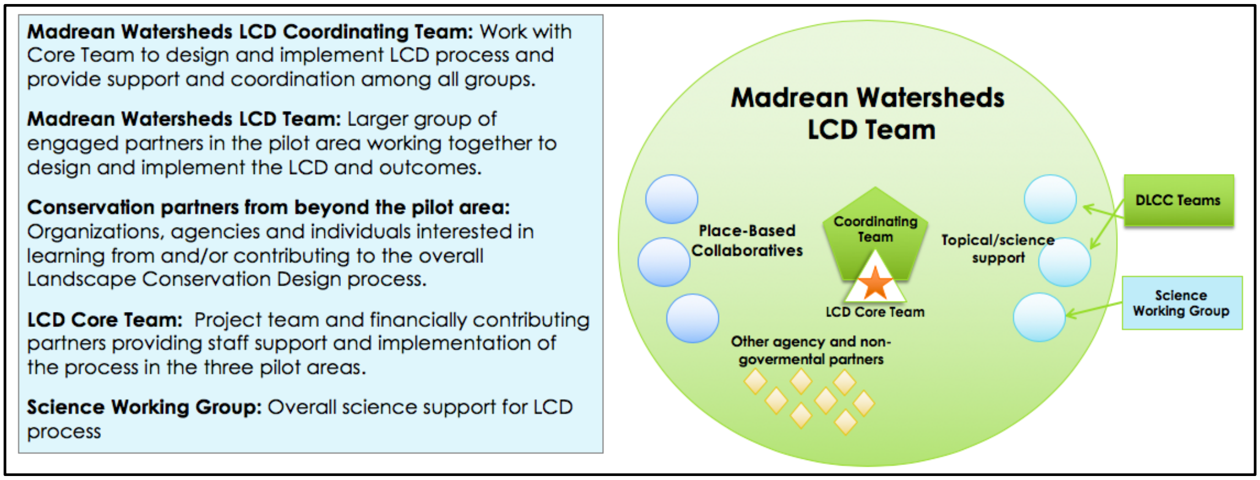

Figure 5. Madrean LCD collaborative structure diagram.

Summary of Key Events and Milestones

The timeline of major partner convenings and events to create the Madrean LCD:

- 2015 Desert LCC workshops: Tucson, Arizona and Aguascalientes, Mexico (Appendix 1a)
- 2015 - 2016: Desert LCC Partner Assessment
- May 2016: Bi-lingual kick-off webinar for partners
- July 2016: Land Managers Focus Group
- September 2016: Madrean LCD Partner Workshop, Tucson, AZ (Appendix 1b)
- August 2017: Lower San Pedro Community Watershed Workshop
- November 2017: Indicator Development Workshop and webinar (Appendix 2a)
- March 2018: Scenario planning focus group with land managers
- May 2018: Madrean Conference (convened by Sky Island Alliance in Tucson, AZ)
- June 2019: Structured Decision Making workshop (Tucson, AZ)
- August 2019: Management Challenges and Strategies webinar
- Coordinating Team calls (bi-monthly or monthly from 2016 - 2019)
- In-person Coordinating Team meetings (ad-hoc)

Vision and Goals

The Vision and Goals for the Madrean LCD were collaboratively created by partners to guide the development of LCD products and outcomes. Input was gathered at partner workshops in 2015 and 2016 and the statements were finalized by the Madrean LCD Coordinating Team.

Vision—The Madrean Watersheds initiative is a large landscape, international effort to maintain and enhance the interconnected system of mountains, grasslands, deserts, and waters that supports species diversity, promotes healthy watersheds, and maintains the overall ecosystem integrity that enriches the lives of human communities.

Goals:

- *Biodiversity*—Transboundary Madrean watersheds are a haven for the unique diversity of native and endemic species.
- *Connectivity*—Enhanced linkages connect the diverse life zones of Sky Island ecosystems, from valley bottoms to mountain tops, from southern Sonora to the Gila River in Arizona, enabling persistence of migratory wildlife and allowing for the possible future shift of species and ecosystems in a changing climate.
- *Socio-Ecological Services*—Healthy watersheds, functioning ecosystems and cultural resources deliver highly valued benefits to human communities.

Chapter 2—Conservation Blueprint

The Madrean Landscape Conservation Design (Madrean LCD) combined geospatial data, biological information, models, and expert knowledge to create an analysis and spatial plan known as the Madrean Conservation Blueprint, that will provide for the enduring conservation of biodiversity, habitats, and environmental processes and services within the landscape. The Conservation Blueprint suggests where protection, conservation, and restoration actions may best contribute to sustaining ecological and social values and functions of the landscape.

The Conservation Blueprint component of the Madrean LCD is an open-access geospatial tool that allows users to view data and derived products in an interactive map viewer and to download data for use in a GIS (available at skyislandalliance.org/madreanlcd). Springs data and analysis is presented in a separate open-access geospatial tool which also allows users to view data and analysis products and to download (https://skyislandalliance.org/library/). The process for creation included:

- collaborative identification of focal ecosystems
- development and analysis of indicators of the health of those focal ecosystems
- creation of maps of biological cores and wildlife corridors
- identification of climate change adaptation actions.

Indicators

A key approach of Landscape Conservation Design is to select indicators – observable components of ecosystems that help interpret ecological conditions, trends, and the effects of conservation actions over time. The suite of indicators selected should represent key information about structure, function, and composition of ecological systems which indicate their ability to support focal resources identified by stakeholders (Dale and Beyeler, 2001). They are meant to be monitored into the future by partners.

The ecosystems of the Madrean LCD are complex and indicators provide a way to simplify modeling and monitoring of those ecosystems. We worked to develop a set of socially relevant indicators that have the power to:

1) Spatially guide and prioritize conservation and restoration within watersheds; and
2) Detect changes in focal ecosystems within and across watersheds
3) Be useful and relevant to natural resource management and conservation goals of partner agencies and organizations related to biological diversity, connectivity and socio-ecological services.

Methodology

The indicator selection process involved the following activities:

- Articulation of goals and fundamental objectives for the Madrean area.
- Identification of focal ecosystems for which to develop indicators.
- Development of a list of potential indicators based on information gathered from partners who were conducting long-term monitoring of ecosystems and expert input.

- Narrowing the list of potential indicators to a shorter, analyzable final list that reflects managers needs by:
    - Assessing indicators against criteria; and
    - Researching availability of data to represent potential indicators.

The detailed selection process is described in the subsequent sections of this report.

Articulation of Goals and Selection of Focal Ecosystems

Indicator selection was guided by both the Madrean LCD vision and goals developed by local partners (see Chapter 1- Madrean LCD Vision and Goals), and general goals articulated by the Desert LCC for all LCDs including the Eastern Mojave and Dos Rios pilot areas which are listed below.

Goals:

- *Ecosystem Integrity*—Maximize the integrity of ecological systems that characterize natural areas and managed landscapes that people care about. Ecological integrity is defined as the ability to support and maintain a balanced, integrated, and adaptive community of organisms having a species composition, diversity and functional organization comparable to those of natural habitats (Karr, J. R. and D. R. Dudley 1981).
- *Landscape Connectivity*—Maximize structural and functional connectivity of the landscape for the movements of genes, propagules (pollen and seeds), individuals, and populations to meet requirements of the organisms that live within it and move through it.
- *Biodiversity*—Ensure the persistence of biological diversity of ecosystems and habitats, including the conservation of species diversity.

We gathered inputs from the Desert LCC steering committee and working groups, and the *Madrean Watersheds Partner Workshops* (2015 & 2016) in order to select focal ecosystems for indicator development. Ecosystems were selected based on their relative importance to achieve biodiversity, connectivity, and socio-economic goals; their distribution across the Madrean Watersheds; the extent to which they face large-scale stressors; and the level of partner engagement in managing them. We developed indicators for the following six ecosystems: streams, springs, riparian, grassland, Sonoran desert scrub, and Madrean evergreen woodland.

Selecting Indicators

To develop a set of indicators that could assess ecological integrity and trends for the focal ecosystems we catalogued those proposed at partner workshops and those currently or previously in use by partners. We reviewed published reports (AZGFD 2012a; CDFW 2015; Chung-MacCoubrey et al. 2008; Comer 2013; Mau-Crimmins 2005; NPS 2010; Waltz et al. 2017) and used expert input collected via a survey on ecosystem stressors (unpublished report, Desert LCC), collected expert input at interactive workshops (Appendix 1b; Appendix 1c), and solicited expert input and review from the Madrean Watersheds Coordinating Team. This generated a list of potential indicators.

Potential indicators were then evaluated on their: 1) value for assessing ecosystem condition, and; 2) ability to measure condition across the full regional extent of the ecosystem. Indicators were classified into the following categories: Good (positive in value and extent), Moderate (positive in value and moderate extent), and Poor (very deficient in assessment extent). With this information in hand, a list of still feasible indicators was brought to Madrean LCD partners to be evaluated and narrowed at an in-person workshop.

We convened a *Madrean Watersheds Indicator Development Workshop* (2017) to assess and narrow the indicators that were classified as Good or Moderate. The workshop was attended by 23 participants including biologists, managers, researchers, and students from the region. Participants worked in ecosystem breakout groups (streams/riparian, springs, grasslands, Sonoran desert-scrub, and Madrean evergreen woodland) to rank and review indicators against criteria (Table 2) which were developed by the Desert LCC Critical Management Team for Landscape Monitoring from the South Atlantic LCC Blueprint (SALCC 2012) and Dale and Beyeler (2001).

Table 2. Criteria for assessment of indicators by partners.

Ecological	• Represent ecological attributes and habitat condition for a suite of organisms and/or ecological attributes • Provide information about changes in important ecosystem condition or processes • Can detect changes over time that occur in response to management actions
Practical	• Are being measured as part of an existing and continuing monitoring program or system, OR can be easily/economically monitored using existing data • Have existing/historic datasets
Social and Cultural	• Can be easily understood by policy-makers and conservation practitioners • Resonate with the public

Finally, breakout groups discussed the potential use, value, and spatial availability of data for these indicators (Appendix 2a). This expert input helped produce a shorter list of 72 indicators grounded in management considerations. We then conducted further research into spatial datasets to support analysis of these indicators and 32 of the indicators were not carried forward due to the constraints of available spatial data. Three different scenarios emerged that limited their usability:

- Some indicators were more suited to project-specific assessments—they were valuable to assess management actions, but not widely monitored at the landscape-scale.
- Some indicators were monitored at the landscape-scale, but were not designed to be spatially-explicit (monitoring completed through random sampling).
- Some indicators were monitored at the landscape scale and were spatially explicit, but they had very coarse resolution, and/or timing and coverage was variable and limited.

The final list of indicators by ecosystem and grouping, notes on why some were not used in analysis, and their corresponding spatial variable and unit of analysis are in Table 3.

Table 3. Final indicators cross referenced with corresponding spatial variable and unit of analysis. Y=Yes, N=No, HHI=Human Influence Index.

	Grouping	Indicator*	Used	Reason/Notes	Corresponding spatial variable	Unit of Analysis - Variable Code			
						HUC12	*Forest Core*	*Grassland Core*	*Connectivity Area*
General	***Protection***	None	Y		Percent Protected	PerProtect	PerProtect	PerProtect	
	Cores & Connectivity	None	Y		Percent Forest Core	FcorePER			
		None	Y		Percent Grassland Core	GcorePER			
		None	Y		Percent Connectivity Area	LinkPER			
	Topography	None	Y		Elevation Range	ElRange			
		None	Y		Topographic Roughness	TRI_mean			
	Human Influence	None	Y		Human Influence Index	HII_mean			HII_mean
		None	Y		Percent Cropland	CropPer			
	Vegetation	None	Y		Percent Tree Cover	CanopyCov			
		None	Y		Percent Tree and Non-tree Cover	2016VegPerCov			
		None	Y		Trend in Tree and Non-tree Cover	VegTrend			

	Grouping	Indicator*	Used	Reason/Notes	Corresponding spatial variable	Unit of Analysis - Variable Code			
						HUC12	*Forest Core*	*Grassland Core*	*Connectivity Area*
Sonoran desert scrub:	***Vegetation***	Vegetation composition - diversity of species	N	Not available					
		Vegetation cover[1] - percentage of ground covered by vegetation	Y		SDS Percent Bare Ground, SDS Trend in Bare Ground, SDS Percent Non-tree Cover, Trend in SDS Non-tree Cover, SDS Percent Tree Cover, SDS Trend in Tree Cover	SDSBG2016, SDSBGTREND, SDSHerb2016, SDSHerbTREND, SDSTree2016, SDSTreeTREND			
		Vegetation - age structure	N	Not available					
	Wildlife	Desert scrub birds	N	Not available					
		Mule deer - density	N	Not available across the pilot area					
	Stressor	Rate of ecosystem change caused by human development[2]	Y	Not available as a rate	Percent SDS, SDS Percent Modified	Per SDS, SDSMod			
Grasslands:	***Extent/ Fragmentation***	Grassland extent – loss per year to agriculture or development[3]	Y	Loss to ag or development not available yearly	Percent Grassland, Grassland Percent Modified	PerGrass, PerGrassMo		PerGrass, PerGrassMo	
		Grassland patches – size, distribution, and class, by watershed[10]	Y		Average Size of Grass Patches, Size of Largest Grass Patch	GrassMeanArea, GrassLPI		GrassMeanArea, GrassLPI	
		Grassland fragmentation index	Y		Number of Grass Patches, Number of Grass Patches Per km^2	GrassNP		GrassNP, GrassNPperkm	
	Wildlife	Pronghorn – presence and trend	N	Not available across the pilot area					
		Regional breeding birds – presence	N	Not available across the pilot area					

	Grouping	Indicator*	Used	Reason/Notes	Corresponding spatial variable	Unit of Analysis - Variable Code			
						HUC12	*Forest Core*	*Grassland Core*	*Connectivity Area*
		Regional wintering birds - presence	N	Not available across the pilot area					
	Ecological condition of ground cover	Ratio of woody brush species to grass species[9]	Y	MODIS VCF was the closes available product. Tree cover in VCF represents tall trees, so may be inaccurate	Grassland Percent Non-tree Cover, Trend in Grassland Non-tree Cover, Grassland Percent Tree Cover, Grassland Trend in Tree Cover, Tree:Non-tree Cover Ratio, Trend in Tree:Non-tree Ratio	GrassHerb2016, GrassHerbTREND, GrassTree2016, GrassTreeTREND		GrassHerb2016, GrassHerbTREND, GrassTree2016, GrassTreeTREND, woodytoherb16, woodtoherbtrend	
		Percent bare ground (NDVI for alternative assessment)[4]	Y	Yes	Grassland Percent Bare Ground, Grassland Trend in Bare Ground,	GrassBG2016, GrassBGTREND		GrassBG2016, GrassBGTREND	
		Invasive versus native grasses - extent (now Group wants composition and cover)	N	Not available					
		Net primary productivity	Y		Summer Growing Season NDVI, Trend in Summer NDVI	2017SummrNDVI, SummerNDVITrend			
	Fire	Fire Frequency (new)	N						
		Departure from fire regime	N						
Madrean evergreen woodland:	***Extent/ Fragmentation***	Madrean evergreen woodland – spatial extent[11]	Y		Percent MEW	PerMEW	PerMEW		
		Patch size[12]	Y		Average Size of MEW Patches, Size of Largest MEW Patch	MEWMeanArea, MewLPI	MEWMean Area, MewLPI		
		Fragmentation index	Y		Number of MEW Patches, Number of MEW Patches Per km^2	MEWNP	MEWNP, MEWNPper km		
	Wildfire frequency,	Wildfire size, extent, and severity[5]	Y		Percent Burned Severely	BurnSev	BurnSev		

	Grouping	Indicator*	Used	Reason/Notes	Corresponding spatial variable	Unit of Analysis - Variable Code			
						HUC12	*Forest Core*	*Grassland Core*	*Connectivity Area*
	extent, severity	Fire regime departure class	N	Only available in US; simplified to just Fire Risk					
		Prescribed fire treatments - number and acreage[18]	N	Not available across the pilot area					
		Fire risk – probabilities across the ecosystem	Y		Percent at Risk of High Burn Severity	BurnRisk	BurnRisk		
		Fuel loading[6]	N	Only available in US; simplified to just Fire Risk					
		Risk of fire to structures in the Wildland-Urban Interface	N	Not available across the pilot area					
		None	Y		Number of High Burn Severity Fires	NumHSFires	NumHSFire s		
	Wildlife	Madrean evergreen bird guild (new)	N	Not available across the pilot area					

<table>
<tr><th rowspan="2"></th><th rowspan="2">Grouping</th><th rowspan="2">Indicator*</th><th rowspan="2">Used</th><th rowspan="2">Reason/Notes</th><th rowspan="2">Corresponding spatial variable</th><th colspan="4">Unit of Analysis - Variable Code</th></tr>
<tr><th>HUC12</th><th>Forest Core</th><th>Grassland Core</th><th>Connectivity Area</th></tr>
<tr><td rowspan="13">Streams:</td><td rowspan="7">Flow</td><td>Continuous perennial flow – maximum length</td><td>Y</td><td></td><td>Length of Longest Perennial Flow</td><td>MaxPerWi_m</td><td></td><td></td><td></td></tr>
<tr><td>Continuous perennial flow – total length[7]</td><td>Y</td><td></td><td>Total Length of Perennial Flow in Watershed</td><td>TotalPerWi_m</td><td></td><td></td><td></td></tr>
<tr><td>None</td><td>Y</td><td></td><td>Total Length of Perennial Flow Watershed is Connected To</td><td>PerConnect_m</td><td></td><td></td><td></td></tr>
<tr><td>Minimum flow[13]</td><td>N</td><td>Postponed</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Maximum flow[14]</td><td>N</td><td>Postponed</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Median flow[15]</td><td>N</td><td>Postponed</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>No flow (days with no flow)[16]</td><td>N</td><td>Postponed</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Groundwater</td><td>Depth to groundwater[17]</td><td>N</td><td rowspan="2">Postponed</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Surrogate: canopy cover[8] where no data</td><td>N</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Groundwater wells – number, volume of water pumped, number of non-exempt wells, etc.</td><td>N</td><td>Postponed</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Wildlife</td><td>Aquatic insects – presence of species indicative of high-quality habitat</td><td>N</td><td>Not available across the pilot area</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Water quality</td><td>Water quality – dissolved oxygen</td><td>N</td><td>Not available across the pilot area</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Development</td><td>Human development within the floodplain</td><td>N</td><td>Postponed</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Springs:</td><td rowspan="2">General</td><td>None</td><td>Y</td><td>See Springs Tool</td><td>Average Conservation Value Score of Springs</td><td>SpringCVMean</td><td></td><td></td><td></td></tr>
<tr><td>None</td><td>Y</td><td>See Springs Tool</td><td>Average Threat Score of Springs</td><td>SpringTMean</td><td></td><td></td><td></td></tr>
</table>

	Grouping	Indicator*	Used	Reason/Notes	Corresponding spatial variable	Unit of Analysis - Variable Code			
						HUC12	*Forest Core*	*Grassland Core*	*Connectivity Area*
		None	Y	See Springs Tool	Distance of Most Isolated Spring From Other Water	SpringIMax			
		None	Y	See Springs Tool	Density of Springs	SpringDens			
		None	Y	See Springs Tool	Number of Springs	NUMsprings			
	Spring-dependent species	Sonoran mud turtle – presence	N	Not available across the pilot area					
		Native amphibians – presence	N	Not available across the pilot area					
		Endemic species – presence	N	Not available across the pilot area					
		Hydro-riparian vegetation – presence	Other	See Springs Tool					
		Aquatic invertebrates – presence of species that indicate high water quality	N	Not available across the pilot area					
	Water quantity	Water discharge – flow SSI: measured flow	Other	See Springs Tool					
		Wetted area (new) SSI: area sq. meters of wetted habitats	N	Not available across the pilot area					
		Persistence of flow in "springshed"	N	Not available across the pilot area					
	Human use of spring	Level of human development, SSI: SEAP avg. of human influence	Other	See Springs Tool					
		Impacts from herbivory – class and status, SSI: SEAP mammalian herbivory condition	Other	See Springs Tool					

	Grouping	Indicator*	Used	Reason/Notes	Corresponding spatial variable	Unit of Analysis - Variable Code			
						HUC12	*Forest Core*	*Grassland Core*	*Connectivity Area*
	"Springshed" condition	Percent of springs located in forests that have departed from their original fire regimes	N	Yes					
		(Spring percentage within) past fire extent in the watershed	N	Yes					
	Natural function of spring in landscape	Usability by wildlife, SSI: SEAP habitat avg.	Other	See Springs Tool					

Spatial Analysis –Delineating Cores and Connectivity Areas

Connectivity for wildlife and ecosystems is a fundamental element of the Madrean LCD vision to maintain and enhance the interconnected system of mountains, deserts, grasslands, and waters across the Sky Islands of the United States and Mexico. Connectivity was of particular interest to the group of partners involved in developing the LCD in part because of the isolated nature of Sky Island mountains and the patchwork of land ownership that makes it difficult for any single organization or jurisdiction to maintain landscape-level connectivity which is vital to maintaining wide-ranging wildlife and ecosystem services.

In order to consider landscape level connectivity partners established a methodology for identifying biological cores, linkages that connect the cores, and pinch points that act as bottlenecks for movement within the linkages. The resulting products can be used to inform decision making in the region:

1. A map of corridors, linkages, and pinch points.
2. A list of existing connectivity models within the Transboundary Madrean Watersheds area.

Methodology

We created a Connectivity Team of experts and interested partners to help us determine the geographic scope of connectivity analysis, proposed methods and products, and to ensure approach and lessons learned in the Madrean LCD was integrated with similar work in Eastern Mojave and Dos Rios LCDs. We identified two main priorities for analyzing connectivity: identify and protect areas currently providing connectivity between Sky Islands; and locate pinch points where connectivity is reduced or threatened and needs to be restored (Appendix 2b). Mapping and analyzing connectivity area necessitates defining and mapping cores to connect. We conducted spatial analyses to produce a map of cores, connectivity areas, and pinch points for the entire Madrean area of interest as well as three localized connectivity models. These products underscore the value of regional-scale, digitized maps to use as a starting point for more localized, action-based decisions.

We digitized forest and grassland "cores" utilizing contiguous blocks of mostly unfragmented (i.e. limited development and no paved roads) Sky Islands mountains with forest ecosystem type communities (i.e., Madrean Evergreen Woodland, Petran Montane Conifer Forest from Brown and Lowe 1981) and large grassland areas (all cores >20 km^2). Below are detailed descriptions of the methodology used to delineate cores and connectivity areas.

Cores

We used the Deyo et al. (2013) digitized map of the Madrean Archipelago as a starting point and removed any areas that contained major or secondary highways or county paved roads where the roads were crossed by major drainages or abutted urban/ex-urban areas.
Forest cores were digitizing based on the Digital Elevation Model (90m) with a hillshade, combined with a Brown and Lowe (1981) vegetation distribution digital map, a Commission for Environmental Cooperation (CEC) North America Land Change Monitoring System (NALCMS

30 m, 2010), and SW ReGAP (2004) digital map for the Southwest. Montane forest cores were selected based on Madrean Evergreen Woodland or Petran Montane Conifer Forest occurrence within the montane core area.

Grassland cores were digitized for mostly contiguous semi-desert grasslands (NALCMS: Tropical or Sub-tropical Grassland or Temperate Grassland) embedded in areas of Chihuahuan desert scrub (NACMS: Tropical or Sub-tropical Shrubland or Temperate Shrubland). The CEC NALCMS, GAP land cover, CEC Human Influence Index (with intent to capture and limit cores to areas of relatively low human influence), 2017 CEC North American Protected Area Database (NA PAD) (with intent to capture protected areas where possible), slope, elevation, and topography were utilized to set or adjust the boundaries of the cores. Finally, we cross-referenced the resulting polygons with three primary sources for grassland in the Madrean region: TNC's Grasslands Assessment GIS Data – Class A grasslands (2004), North American Priority Conservation Areas: Grasslands (CEC et al. 2010), and TNC's Sky Island Grassland Assessment (Gori et al. 2012). Where necessary, we expanded our digitized polygons to include areas mapped by these studies.

Connectivity Areas

We mapped areas through which wide-ranging vertebrate species could most efficiently and safely move through the fragmented landscape. Wide-ranging species function among many population centers but have primary population centers in large blocks of high-quality habitat that are the least fragmented and least disturbed by development. These species must move between forest and grassland cores. Threats to connectivity include the following major barriers: 1) the U.S./Mexico international border and associated infrastructure; 2) major highways; 3) secondary highways 4) cities and ex-urban and rural communities, 5) resource extraction areas such as mines, and 6) linear utility infrastructure including railroads, pipelines, and transmission lines. We digitized connectivity areas by utilizing existing linkage/corridor models, adding additional areas to connect cores across or between current and potential future barriers (based on known plans for future development) and, where possible, designed connectivity areas to reach lands managed for conservation of wildlife and their habitats. The following GIS layers[2] were used to delineate connectivity area polygons:

- Least-Cost Wildlife linkage models (AZGFD 2012b and P. Beier et al. 2006, 2008, Arizona Missing Linkages Project, see Appendix 2Ca)
- Circuitscape jaguar models (Stoner et al. 2015; Theobald 2017)
- Roadkill data on Mexico Highway 2 (unpublished data, Sky Island Alliance and Wildlands Network)
- Human Modification for North America (270m; Theobold 2013)

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[2] *Note that not all GIS datasets were available across the entire Madrean LCD.*

- Human Influence Index for North America (Wildlife Conservation Society (WCS) and Center for International Earth Science Information Network (CIESIN), 2005, see Appendix 2c)
- Cost Surface Arizona (30m; Green Infrastructure Center, Inc. ESRI 2017)
- Intact Habitat Cores for Arizona (At least 100 acres in size and greater than 100 m wide, Green Infrastructure Center, Inc. ESRI 2017)
- Flow lines (NHD_PlusV2, https://www.epa.gov/waterdata/get-nhdplus-national-hydrography-dataset-plus-data)
- Land Cover (30m) (North American Land Change Monitoring System, NALCMS, produced by CEC 2010, NALCMS 2010)
- Terrain – Land Facets (30m; World Ecological Facets Landform Classes, ESRI 2017)
- Land Ownership (BLM Surface Management)
- Protected land status/Conservation easements
- Aerial imagery – roads/development (ESRI 2018)
- Aerial imagery – pinch point crossing structures (ESRI 2018)

After creating connectivity areas from the layers above, we performed a width check on each area which placed the following size requirements on linkages:

- A minimum width of 1000 meters where the distance between cores was less than 5 kilometers.
- A minimum width of 2000 meters where the distance between cores was greater than 5 kilometers.

Linkages meeting the size requirements then were refined to connect with the identified cores, public lands in the U.S., and protected lands in Mexico. Finally, known pinch points within the connectivity were added (based on prior studies as well as some ground truthing). The initial map of Forest Cores, Grassland Cores, Connectivity Areas, and Pinch Points was presented and discussed at the 2018 Madrean Conference. Partners in the region commented on and added features to the maps, as well as suggested strategies for improving and/or maintaining linkages and other conservation opportunities. The map was updated based on partners' comments in 2019. A map of the connectivity areas and pinch points as well as all previously mapped corridors is available as a shapefile on Sciencebase (https://www.sciencebase.gov/catalog/item/5ea2090f82cefae35a1919cd).

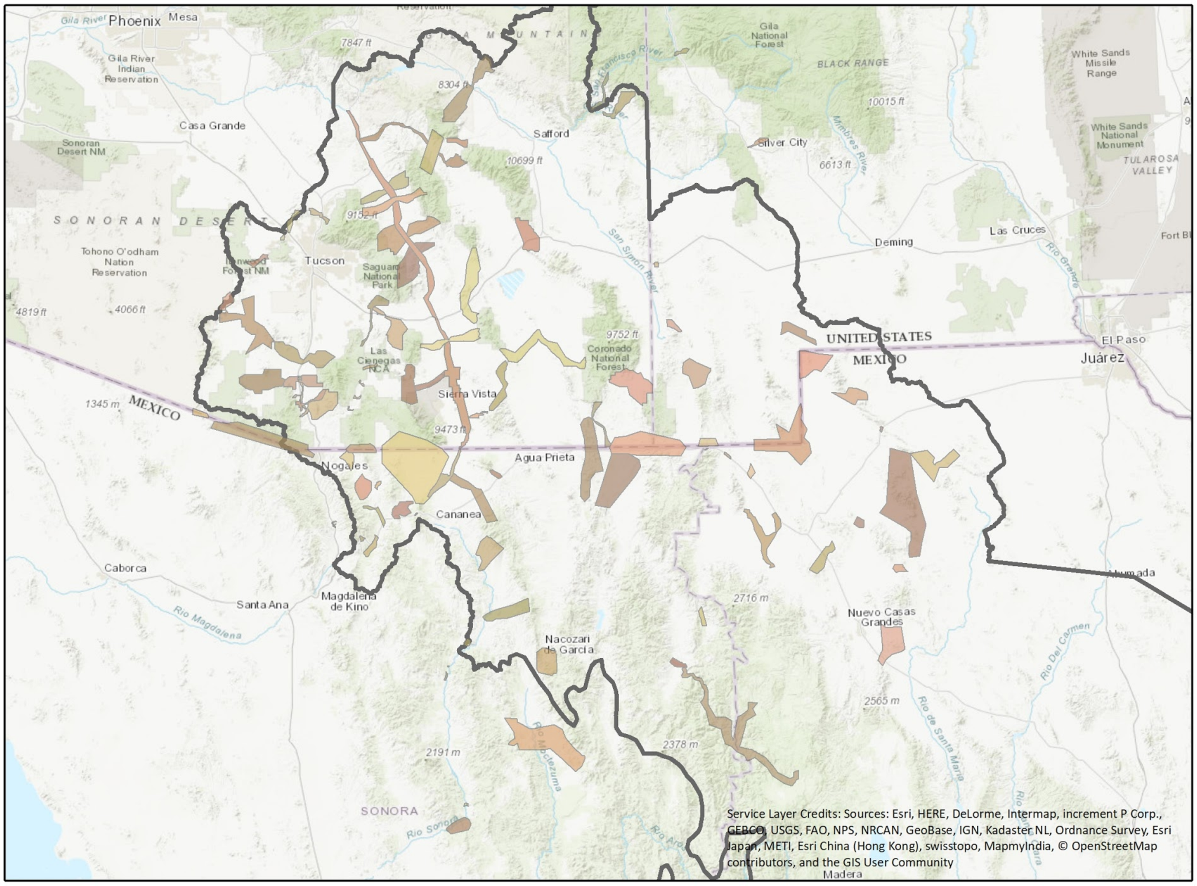

Figure 6. Illustrates Connectivity Areas Delineated by Sky Island Alliance.

Spatial Analysis – Condition and Trends

We chose HUC 12 sub-watersheds as our primary unit of analysis. These watersheds are small enough that they present a reasonable scale for prioritizing on the ground actions. They also capture common eco-hydrological, geological, and abiotic conditions (e.g., similar soils, run-off properties, aquifer depth, temperature profiles, etc.). Conservation and restoration actions, including management actions, also would likely be implemented across varying ecosystem-types within a local sub-watershed, and not confined to individual ecosystem communities. We assessed landscape condition, pattern, fragmentation, and trends for select ecosystems (forest and grassland) conditions within wildland “cores” and the connectivity areas between them. For each analysis unit (watersheds and cores), we analyzed the combination of a subset of variables to provide insight into specific management concerns (see Chapter 3—Management Challenges and Opportunities).

Methodology

Spatial data were selected to match the indicators as closely as possible (Table 3). For riparian indicators, and most stream indicators, analysis was postponed until a future project. This was due in part to a lack of existing data delineating riparian areas which are zones around streams. This data is being produced by the Arizona Game and Fish Department and could be analyzed using these methods at a future data. Stream and groundwater data is sparse in the region which hindered our ability to analyze the chosen indicators. For springs, a detailed examination of springs in the U.S. can be found in the Sky Island Spring Prioritization Tool 1.0, (skyislandalliance.org/library/) from which we pulled several variables to include in spatial analysis. Some indicators did not have any currently available corresponding spatial data so we were not able to analyze them here (Table 3).

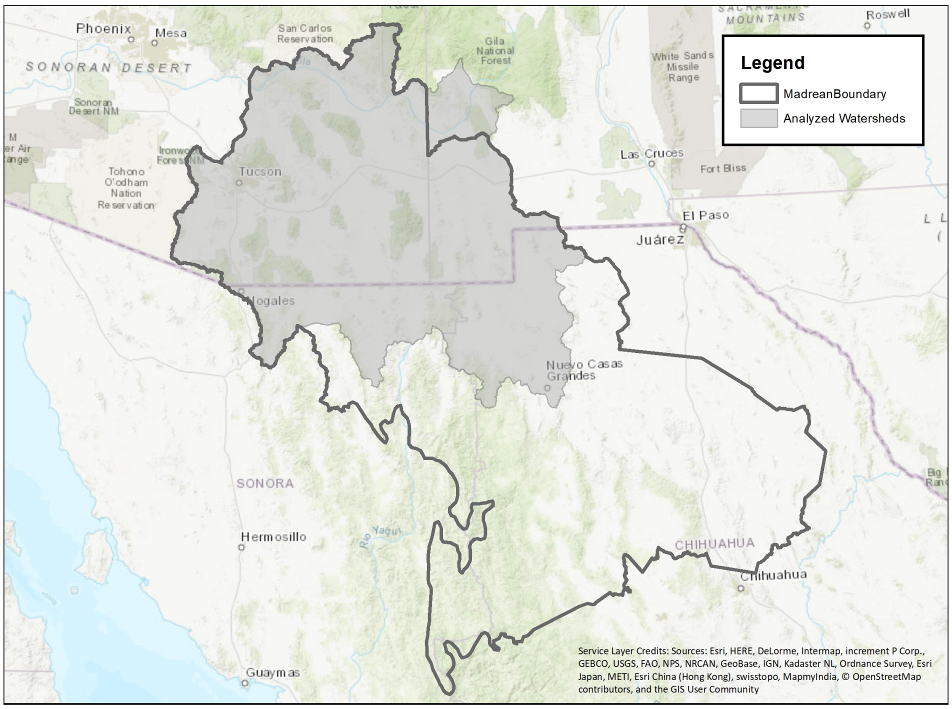

Figure 7. Madrean Pilot Area and smaller area in which HUC12 watersheds were analyzed.

To conduct the spatial analysis of indicators, we reduced our analysis area from the entire Madrean Watersheds to a subset of 14 HUC8 watersheds that are within the U.S. or cross the U.S.–Mexico border. We selected these watersheds because they contain the major rivers of the area (Gila River, San Pedro River, Santa Cruz River, and Rio Yaqui) and because they have watershed boundary data available for the portion in Mexico. Spatial data were summarized at the HUC12 watershed (a small geographic unit bound by topographic and hydrological influence), Forest Core, and Grassland Core scales. HUC12 watersheds were only available for a portion of the pilot area in Mexico, so that analysis is limited to a smaller area than the original pilot area (Figure 7).

For connectivity areas, we created one ArcGIS shapefile that contains not only the connectivity areas described above, but also all mapped linkages and corridors known in the pilot area. This includes data from Wilbor (2014), Atwood et al (2011), the AZ Missing Linkages Project, the AZGFD Pima County Wildlife Connectivity Assessment, Menke (2008), Hass (2001), and Majka (AZ Missing Linkages Project).

Table 3 indicates to which indicator spatial data variables correspond, and at which scale the variable was analyzed. All variables (Appendix 2c) are available in four spreadsheets - the HUC12 database, the Forest Cores database, the Grassland Cores database, and the Connectivity Areas database, as well as in shapefile format (https://www.sciencebase.gov/catalog/item/5d9647a3e4b0c4f70d110f48). To enable comparisons and combinations of variables, we rescaled all data to a scale of 0-100, except trend data, which was rescaled from -100 to +100. For each analysis unit (watersheds and cores), we analyzed the combination of a subset of selected variables to provide insight into specific management concerns.

Forest Cores

Management Concern—In forested areas of the Madrean Watersheds pilot area, permanent loss of forest core to high severity wildfire is a major concern.

To understand which Forest Cores are most threatened by high severity wildfire, we combined the BurnRisk (percent of the core at risk for high severity fire) and MEWMeanArea (average size of forest patches in the core) variables. We divided cores into four groups:

- *High Burn Risk, Small Patches:* cores in the top 25% of BurnRisk and bottom 50% of MEWMeanArea
- *High Burn Risk, Large Patches:* cores in the top 25% of BurnRisk and top 50% of MEWMeanArea
- *Low Burn Risk, Small Patches:* cores in the bottom 75% of BurnRisk and bottom 50% of MEWMeanArea
- *Low Burn Risk, Large Patches:* cores in the bottom 75% of BurnRisk and top 50% of MEWMeanArea

Some cores also have no risk of high severity fire (BurnRisk here represents the percent of the core at risk of high severity fire. Cores with high burn risk and small patches may be most in danger of losing significant portions of forest habitat, while those with low or no burn risk and large patches may be in the least danger. We also did the same analysis for HUC12 watersheds with ≧ 5% forest cover (). This analysis shows which watersheds have forest at high risk.

Grassland Cores

Management Concern—In the grasslands of the pilot area, woody encroachment and human modification (agricultural expansion and other development) are major threats.

To examine woody encroachment, we looked at GrassTreeTREND, which is the trend in the average percent tree cover from 2000-2016, calculated as the slope of the best-fit line to all yearly data points. We divided cores into quartiles of GrassTreeTREND, including four quartiles for positive trends (top 25, top 50, bottom 50, and bottom 25), and one category for a negative trend in tree cover (trees decrease). Cores in the top 25 are the most likely to be experiencing invasion by woody plants, while cores in the trees decrease category may be increasing in grassland cover.

To examine human modification, we first averaged GrassMeanArea (the average size of grassland patches) and GrassHerb2016 (the percent of grassland that was not tall trees or bare ground) to obtain a measure of grassland quality (GoodGrass). This calculation assumes that larger patches of grassland with higher non-tree vegetation cover are better quality. However, it does not contain any information about grass species, so is inherently limited. We then combined this measure of grassland quality, GoodGrass, with PerGrassMo, the percent of the core that humans had converted to urban or built-up areas, or cropland. We divided cores into four groups:

- *Good Grassland, High Modification:* the top 25% of GoodGrass and top 25% of PerGrassMo
- *Good grassland, Low Modification:* cores in the top 25% of GoodGrass and bottom 75% of PerGrassMo
- *Poor to Moderate Grassland, Low Modification:* cores in the bottom 75% of GoodGrass and bottom 75% of PerGrassMo
- *Poor to Moderate Grassland, High Modification:* cores in the bottom 75% of GoodGrass and top 25% of PerGrassMo

Cores with good grassland and high modification may be most in danger of losing significant areas of high quality grassland habitat. We also did the same two analyses for HUC12 watersheds with ≧ 5% grassland cover. This analysis shows which watersheds have grassland suffering from woody invasion and high quality grassland at high risk of loss to human modification.

Water Scarcity

Management Concern—In the Madrean Watersheds pilot area, water availability and maintaining perennial stream and spring flow are major concerns.

Within HUC12 watersheds, we assessed water scarcity. For all watersheds, we used the TotPerWi_m (the total length of perennial stream in the watershed, rescaled from 0-100) to display perennial stream scarcity (Figure X). Using this calculation, watersheds with lower values have greater perennial stream scarcity. Streams in watersheds with scores very close to but greater than zero may be especially worth protecting, as they are very rare water sources in their area.

For only watersheds in the US, we also calculated a water scarcity score by averaging TotPerWi_m (the total length of perennial stream in the watershed, rescaled from 0-100), and SpringDens (the number of springs per square km, rescaled from 0-100). This value was not calculated for watersheds in Mexico, due to the lack of mapped springs in the country. Using this calculation, watersheds with lower values have greater water scarcity. Streams and springs in watersheds with scores very close to but greater than zero may be especially worth protecting, as they are very rare water sources in their area.

Sonoran Desert Scrub

Management Concern—For Sonoran Desert Scrub (SDS), major threats include the conversion of bare ground and native vegetation to herbaceous invasives, including buffelgrass (*Cenchrus ciliaris*), Sahara mustard (*Brassica tournefortii*), and others, as well as conversion of intact SDS to human built-up areas or cropland.

For all SDS analyses, we only analyzed watersheds in which Brown and Lowe (1981) mapped SDS, and the percent of tropical or sub-tropical shrubland from the NALCMS (2010) was ≧ 5.

To examine the conversion of bare ground and native vegetation to herbaceous invasives, we combined SDSHerbTrend (within Brown & Lowe's "Arizona Upland Subdivision" in the HUC12, the trend in average percent non-tree cover from 2000-2016, calculated as the slope of the best-fit line to all yearly data points) and SDSBGTrend (within Brown & Lowe's "Arizona Upland Subdivision" in the HUC12, the trend in average percent bare ground from 2000-2016, calculated as the slope of the best-fit line to all yearly data points). We divided watersheds into four groups:

- *Strong Herbaceous to Bare ground Trend:* watersheds with the 50% most negative SDSHerbTrend and 50% most positive SDSBGTrend
- *Strong Bare ground to Herbaceous Trend:* watersheds with the 50% most positive SDSHerbTrend and 50% most negative SDSBGTrend
- *Weak Herbaceous to Bare ground Trend:* watersheds with the 50% least negative SDSHerbTrend and 50% least positive SDSBGTrend
- *Weak Bare ground to Herbaceous Trend:* watersheds with the 50% least positive SDSHerbTrend and 50% least negative SDSBGTrend

Some watersheds had another combination of trends. Watersheds with a strong bare ground to herbaceous trend may be experiencing invasion of buffelgrass or nonnative annuals. To examine the risk of conversion from native SDS to human modification, we combined PerSDS (Percent of HUC12 that is "Tropical or sub-tropical shrubland", according to the 2010 NALCMS) and SDSMod (within Brown & Lowe's "Arizona Upland Subdivision" in the HUC12, the percent "Cropland" and "Urban and built-up" combined , according to the 2010 NALCMS). We divided watersheds into four groups:

- *Abundant SDS, High modification:* watersheds in the top 50% of PerSDS and top 25% of SDSMod
- *Less SDS, High modification:* watersheds in the bottom 50% of PerSDS and top 25% of SDSMod
- *Abundant SDS, Low modification:* watersheds in the top 50% of PerSDS and bottom 75% of SDSMod
- *Less SDS, Low modification:* watersheds in the bottom 50% of PerSDS and bottom 75% of SDSMod

Watersheds with abundant SDS and high modification may be most in danger of losing significant areas of high quality SDS habitat.

Connectivity Areas

Management Concern—For connectivity areas, one of the greatest concerns is loss of connectivity due to human use of the area.

To look at which corridors were most at risk, we calculated the mean value of the Human Influence Index (HII) (Theobald 2013) within each Connectivity Area. Areas with higher HII values are at greater risk of loss of connectivity.

Spatial Analysis - Results and Interpretation

Forest Cores

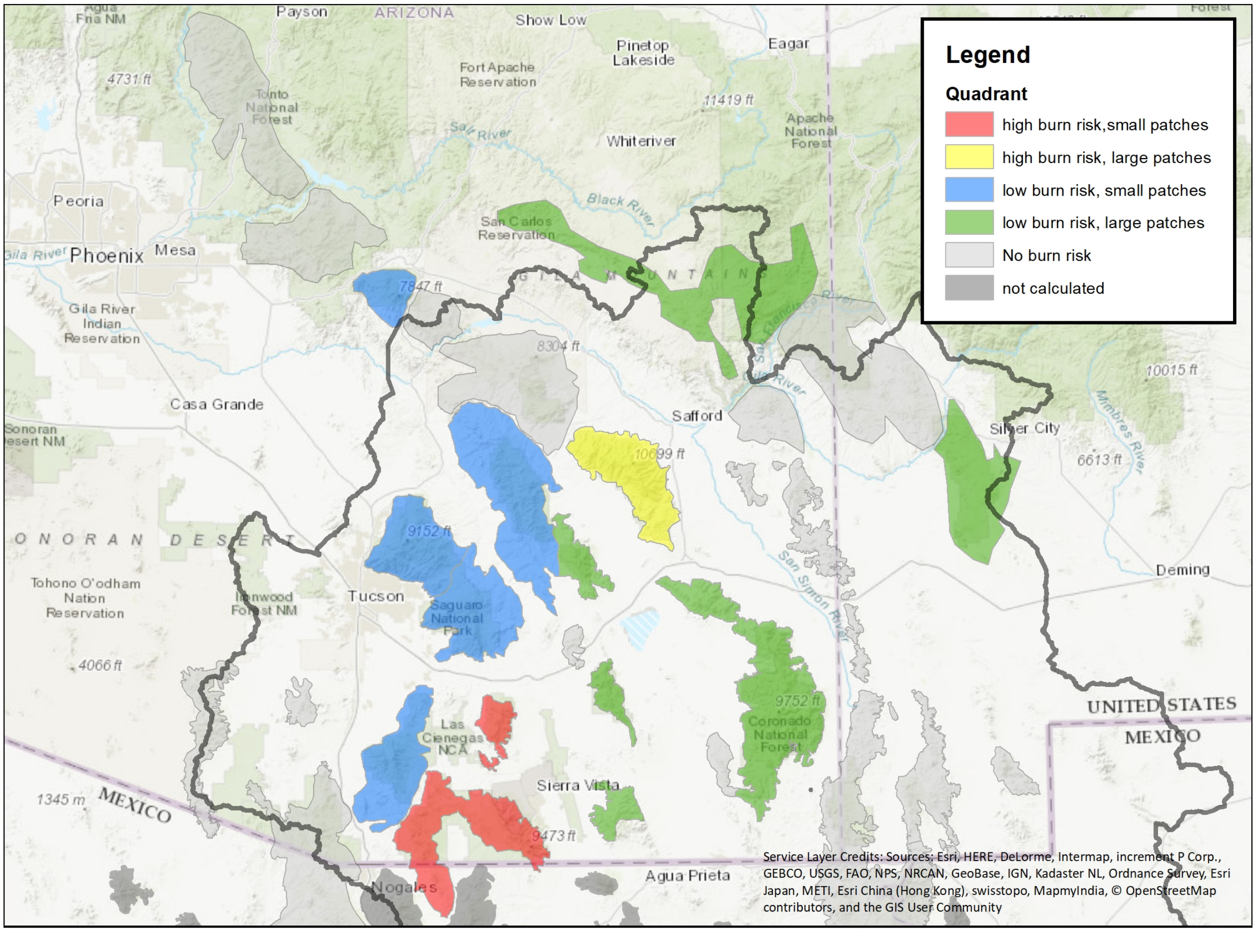

Figure 8. Forest Cores, color coded by burn risk/patch size category.

Legend description

- *High Burn Risk, Small Patches:* cores in the top 25% of BurnRisk and bottom 50% of MEWMeanArea
- *High Burn Risk, Large Patches:* cores in the top 25% of BurnRisk and top 50% of MEWMeanArea
- *Low Burn Risk, Small Patches:* cores in the bottom 75% of BurnRisk and bottom 50% of MEWMeanArea
- *Low Burn Risk, Large Patches:* cores in the bottom 75% of BurnRisk and top 50% of MEWMeanArea

Interpretation

To be in the top 25% of BurnRisk, cores had to have >3% at risk of high burn severity. To be in the bottom 50% of MEWMeanArea, the average patch size had to be <154 square meters. Fifty Forest Cores (63%) were solely in Mexico, so had no BurnRisk score available and were excluded from the analysis. Fifteen Forest Cores partially or wholly in the US had no risk of high severity fire, based on the spatial data we used to calculate fire risk (Figure 8). It is unlikely that these cores truly have no risk of high severity fire, but they are probably the cores that managers can be least worried about. Two cores, the Huachuca-Patagonia core and the Whetstone core, were in the category of most concern - high burn risk and small patches. These cores have larger areas at risk of high severity fire and smaller patches of forest, making them most at risk of losing forest to fire. The distribution of cores in each category is in Table 4.

Table 4. Distribution of Forest Cores in fire risk and patch size categories. Cores solely in Mexico were excluded due to lack of data.

Category	**Count**	**Percent (of analyzed)**
High burn risk, small patches	2	7%
High burn risk, large patches	1	3%
Low burn risk, small patches	5	17%
Low burn risk, large patches	6	21%
No high severity burn risk	15	52%

Grassland Cores

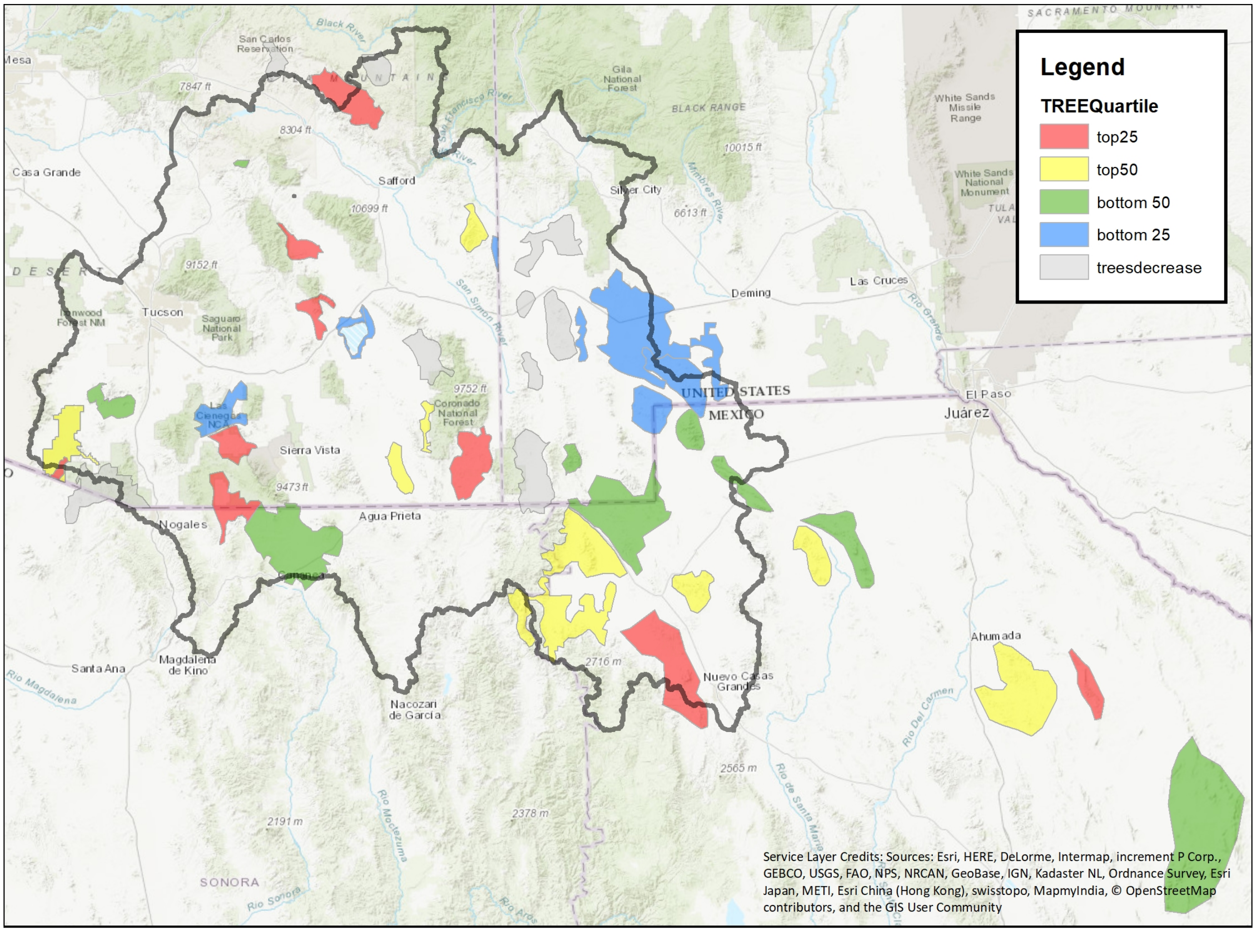

Figure 9. Grassland Cores, color coded by tree trend quartile.

Legend description:
The quartiles represent the trend in the average percent tree cover from 2000-2016, calculated as the slope of the best-fit line to all yearly data points. We divided cores into quartiles of GrassTreeTREND, including four quartiles for positive trends where tree cover is increasing (top 25 - 25% increasing most strongly, top 50 - increasing strongly, bottom 50 - increasing moderately, and bottom 25 - increasing slightly), and one category for a negative trend in tree cover (trees decrease).

Interpretation

To be in the top 25% of woody encroachment, Grassland Cores had to have > +7.5% GrassTreeTrend; to be in the tp 50%, > +3% GrassTreeTrend, and to be in the bottom 25%, < +1.7% GrassTreeTrend. The nine cores with the greatest increases in tree cover were the Buenos Airies NWR Grassland, Severin Canyon, Galiuro Oak Creek, Janos Valley South, Bonita Creek, Sierra del Fierro, San Rafael Valley, San Bernardino Valley, and South Sonoita Valley (Figure 9) Two of these cores are in Mexico, while the rest are in the US. Nine (20%) of the Grassland Cores had decreasing trends in tree cover, so are likely of least concern. These core were Animas Valley Mid, Animas Valley I10, Pyramid, Antelope Flats, S of the Gila, Animas Valley, Big Prairie, Pajarita Mountain Grassland, and Pinery Creek.

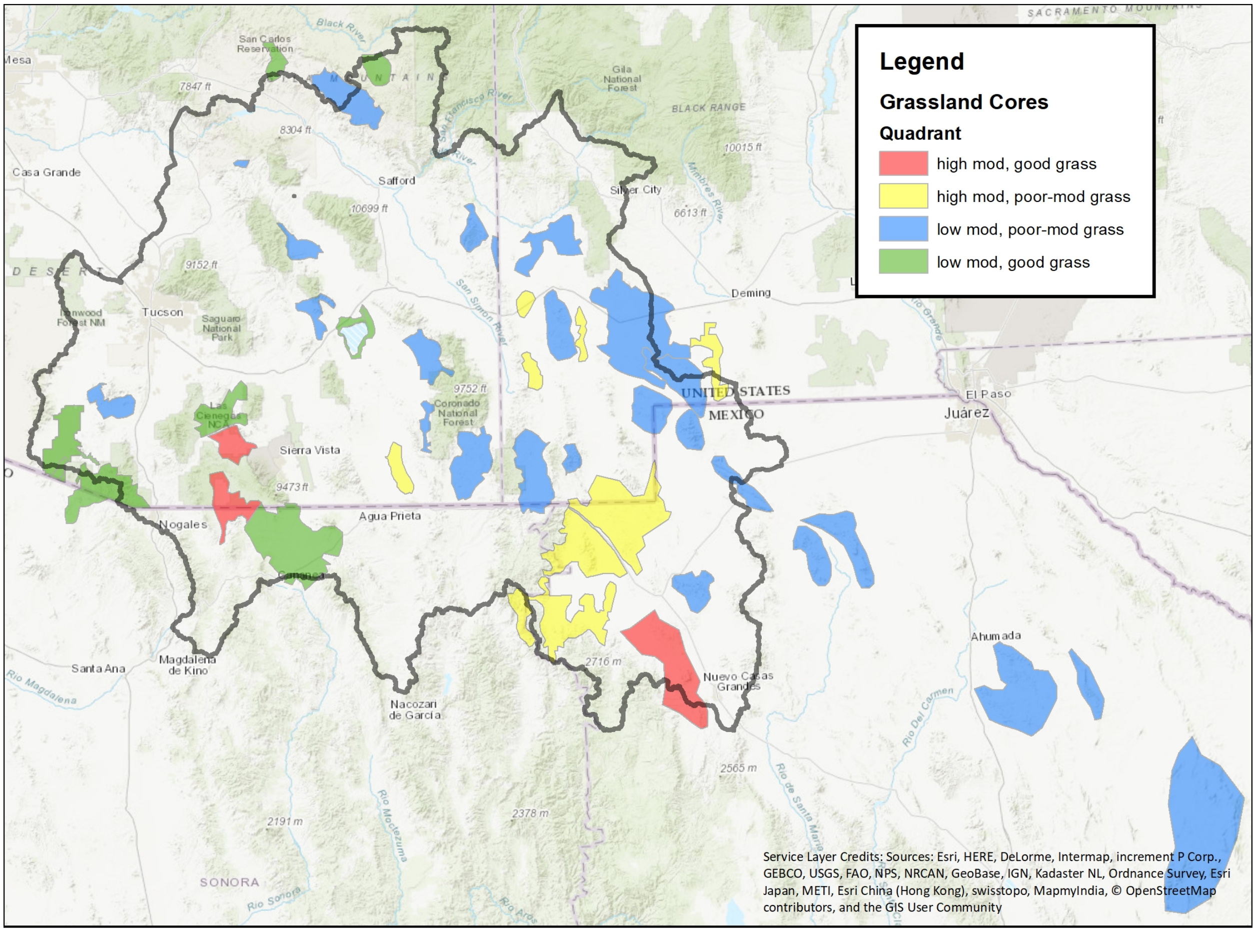

Figure 10. Grassland Cores, color coded by human modification/grassland quality category.

Legend description:

- *Good Grassland, High Modification:* the top 25% of GoodGrass and top 25% of PerGrassMo
- *Good grassland, Low Modification:* cores in the top 25% of GoodGrass and bottom 75% of PerGrassMo
- *Poor to Moderate Grassland, Low Modification:* cores in the bottom 75% of GoodGrass and bottom 75% of PerGrassMo
- *Poor to Moderate Grassland, High Modification:* cores in the bottom 75% of GoodGrass and top 25% of PerGrassMo

Interpretation

To be in the top 25% of grassland quality (GoodGrass), cores had to have an average GrassMeanArea (rescaled from 0-100, the average size of grassland patches) and GrassHerb2016 (rescaled from 0-100, the percent of grassland that was not tall trees or bare ground) >36. To be in the top 25% of PerGrassMo, the percent of the grassland modified by humans had to be > 1%. Three cores, South Sonoita Valley, San Rafael Valley, and Janos Valley South, were in the category of most concern - good grassland with high modification (Figure 10). These cores have higher non-tree vegetation cover, larger patches, but greater human modification, making them potentially most at risk of losing quality grassland to human development. All three of these cores were also in the top quartile of tree encroachment. The distribution of cores in each category is in Table 5.

Table 5. Distribution of Grassland Cores in grassland quality and human modification categories.

Category	Count	Percent
Good grassland, high modification	3	7%
Poor to moderate grassland, high modification	8	18%
Poor to moderate grassland, low modification	25	57%
Good grassland, low modification	8	18%

HUC12 Watersheds - Forests

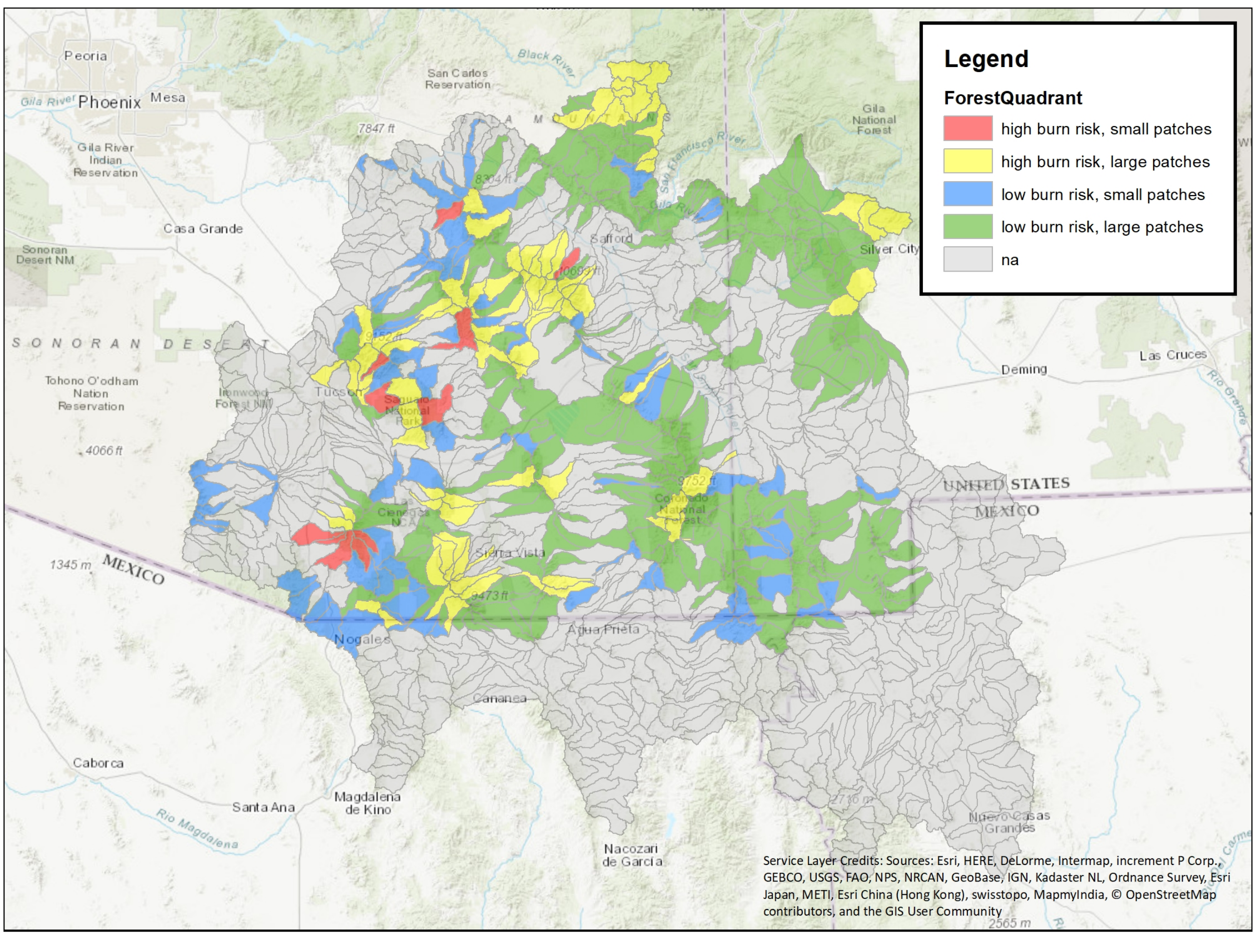

Figure 11. HUC12 watersheds, color coded by burn risk/patch size category.

Legend description:

- *High Burn Risk, Small Patches:* watersheds in the top 25% of BurnRisk and bottom 50% of MEWMeanArea
- *High Burn Risk, Large Patches:* watersheds in the top 25% of BurnRisk and top 50% of MEWMeanArea
- *Low Burn Risk, Small Patches:* watersheds in the bottom 75% of BurnRisk and bottom 50% of MEWMeanArea
- *Low Burn Risk, Large Patches:* watersheds in the bottom 75% of BurnRisk and top 50% of MEWMeanArea

Interpretation

In HUC12 watershed analysis of forests, 238 watersheds in Mexico were excluded due to lack of burn severity data in the country. Another 189 watersheds in the US were excluded because they were < 5% forested. For the remaining 359 watersheds, to be in the top 25% of BurnRisk, watersheds had to have >0.4% at risk of high burn severity. To be in the bottom 25% of MEWMeanArea, the average patch size had to be <85.63 square meters. Eleven watersheds, primarily in the Santa Rita Mountains and Rincon Mountains, with one watershed in each of the Galiuro Mountains, Santa Teresa Mountains, and Pinaleño Mountains, were in the category of most concern - high burn risk and small patches (Figure 11). These watersheds have larger areas at risk of high severity fire and smaller patches of forest, making them most at risk of losing forest to fire. The distribution of watersheds in each category is in Table 6 .

Table 6. Distribution of watersheds in fire risk and patch size categories. Watersheds with a BurnRisk of zero are included in the low burn risk category. Those solely in Mexico were excluded due to lack of data.

Category	Count	Percent (of analyzed)
High burn risk, small patches	11	2%
High burn risk, large patches	79	14%
Low burn risk, small patches	79	14%
Low burn risk, large patches	190	35%

HUC12 Watersheds - Grasslands

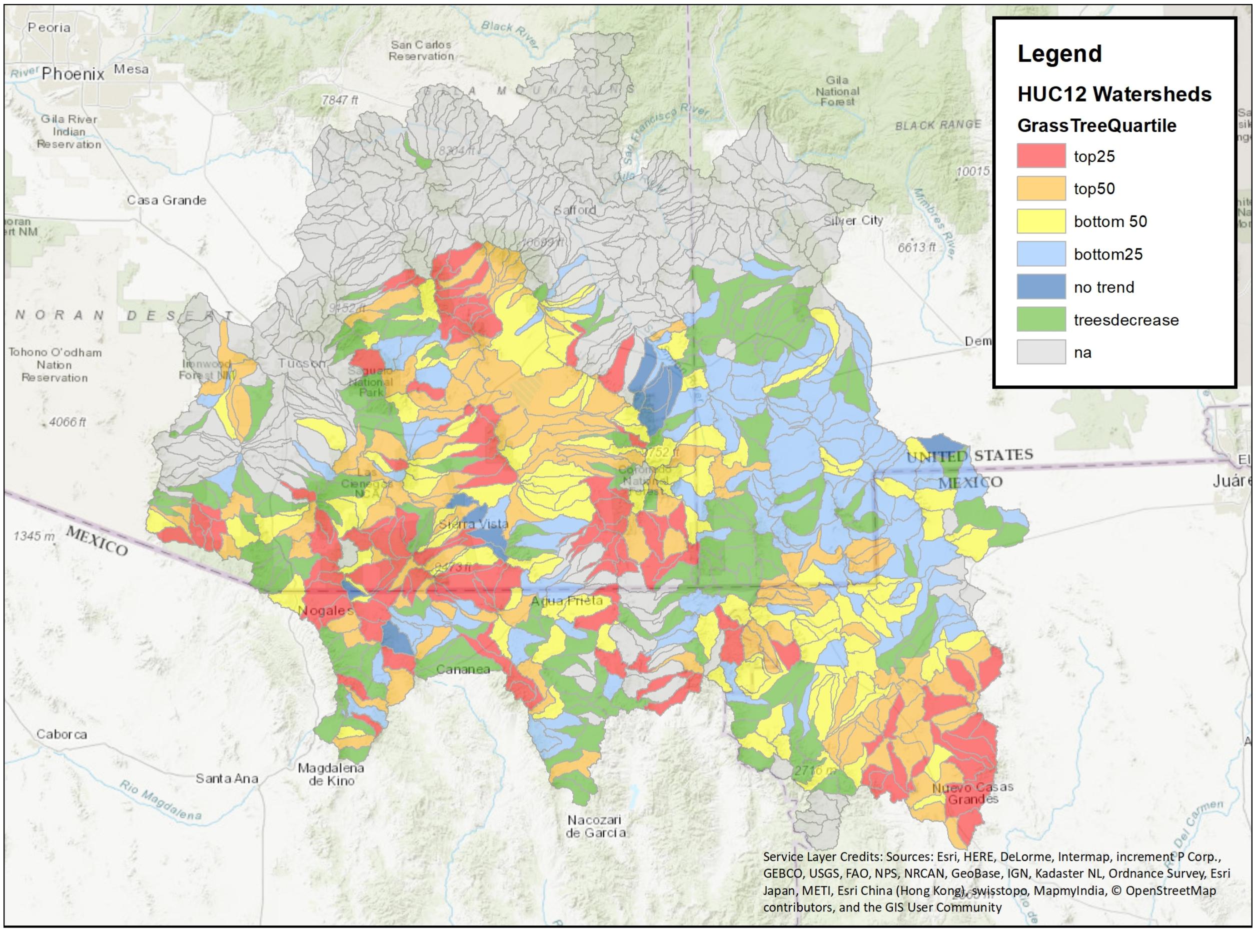

Figure 12. HUC12 watersheds, color coded by tree trend category within their grasslands.

Legend description:
The quartiles represent the trend in the average percent tree cover from 2000-2016, calculated as the slope of the best-fit line to all yearly data points. We divided cores into quartiles of GrassTreeTREND, including four quartiles for positive trends where tree cover is increasing (top 25 - 25% increasing most strongly, top 50 - increasing strongly, bottom 50 - increasing moderately, and bottom 25 - increasing slightly), and one category for a negative trend in tree cover (trees decrease).

We excluded 293 watersheds because they were < 5% grassland.

Interpretation

To be in the top 25% of woody encroachment, watersheds had to have > +7.29742% GrassTreeTrend; to be in the top 50%, > +3.435% GrassTreeTrend, and to be in the bottom 25%, < +1.52% GrassTreeTrend. The top 25% of watersheds with the strongest trends in increasing tree cover comprised 110 watersheds (Figure 12). No trend was seen in 12 watersheds. One hundred forty-three (24%) of the watersheds had decreasing trends in tree cover in their grasslands, so are likely of least concern. The distribution of watersheds in each category is in

Table 7.

Table 7. Distribution of watersheds in tree invasion trend categories.

Category	Count	Percent
Top 25% trees increasing trend	110	18%
Top 50% trees increasing trend	110	18%
Bottom 50% trees increasing trend	110	18%
Bottom 25% trees increasing trend	111	19%
No Trend	12	2%
Trees decreasing	143	24%

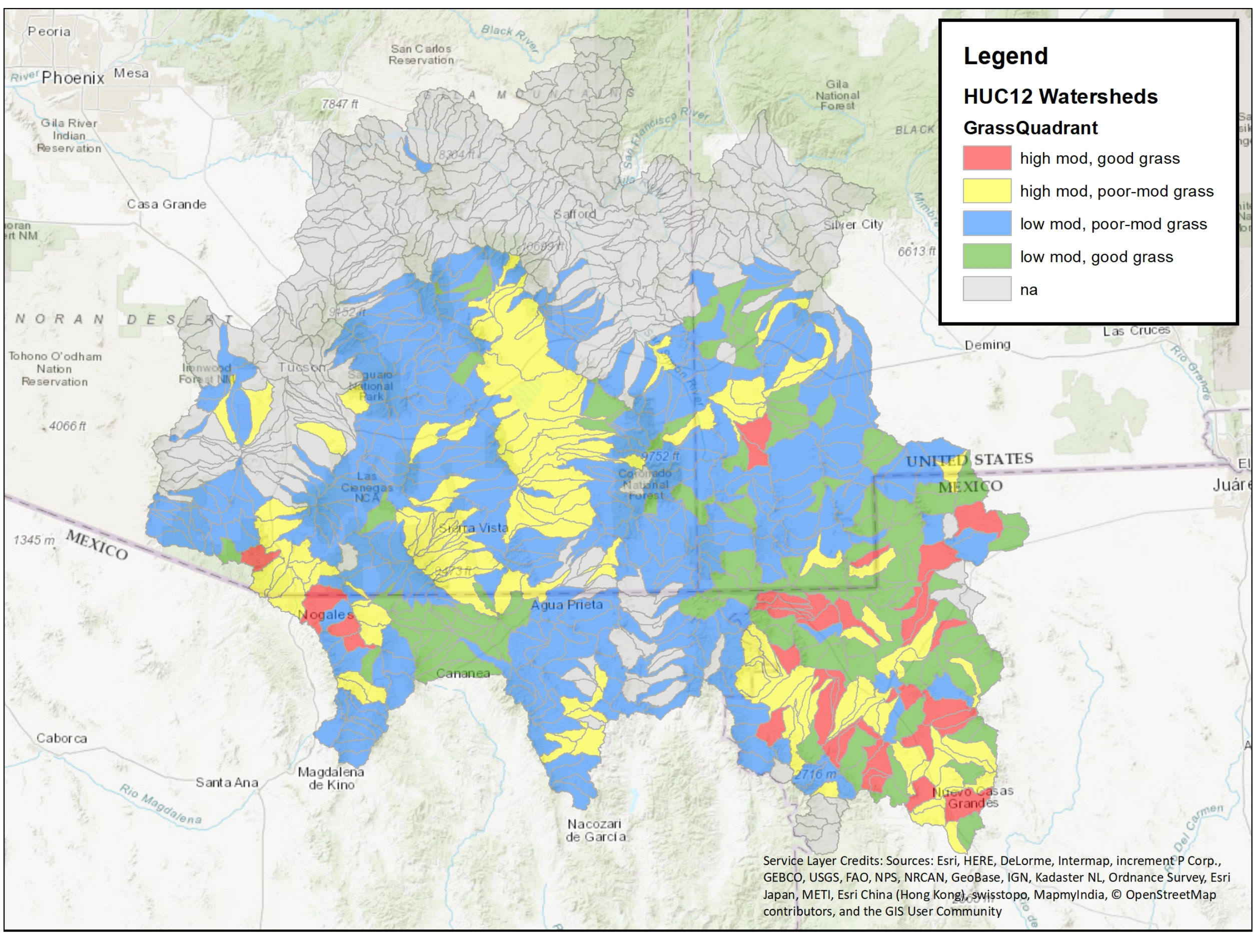

Figure 13. HUC12 watersheds, color coded by human modification/grassland quality category within their grasslands.

Legend description:

- *Good Grassland, High Modification:* the top 25% of GoodGrass and top 25% of

PerGrassMo
- *Good grassland, Low Modification:* cores in the top 25% of GoodGrass and bottom 75% of PerGrassMo
- *Poor to Moderate Grassland, Low Modification:* cores in the bottom 75% of GoodGrass and bottom 75% of PerGrassMo
- *Poor to Moderate Grassland, High Modification:* cores in the bottom 75% of GoodGrass and top 25% of PerGrassMo

Interpretation

To be in the top 25% of grassland quality (GoodGrass), watersheds had to have grasslands with an average GrassMeanArea (rescaled from 0-100, the average size of grassland patches) and GrassHerb2016 (rescaled from 0-100, the percent of grassland that was not tall trees or bare ground) > 29.54. To be in the top 25% of PerGrassMo, the percent of the grassland in the watershed modified by humans had to be > 2.92%. Thirty-seven watersheds were in the category of most concern - good grassland with high modification (Figure 13). Most of these were in Mexico, in the state of Chihuahua, where the primary threat is conversion to agriculture. These watersheds have higher non-tree vegetation cover, larger patches, but greater human modification, making them potentially most at risk of losing quality grassland to human development. The distribution of watersheds in each category is in Table 8.

Table 8. Distribution of HUC12 watersheds in grassland quality/human modification categories.

Category	**Count**	**Percent**
Good grassland, high modification	37	6%
Poor to moderate grassland, high modification	112	19%
Poor to moderate grassland, low modification	335	56%
Good grassland, low modification	112	19%

HUC12 Watersheds - Sonoran Desert Scrub

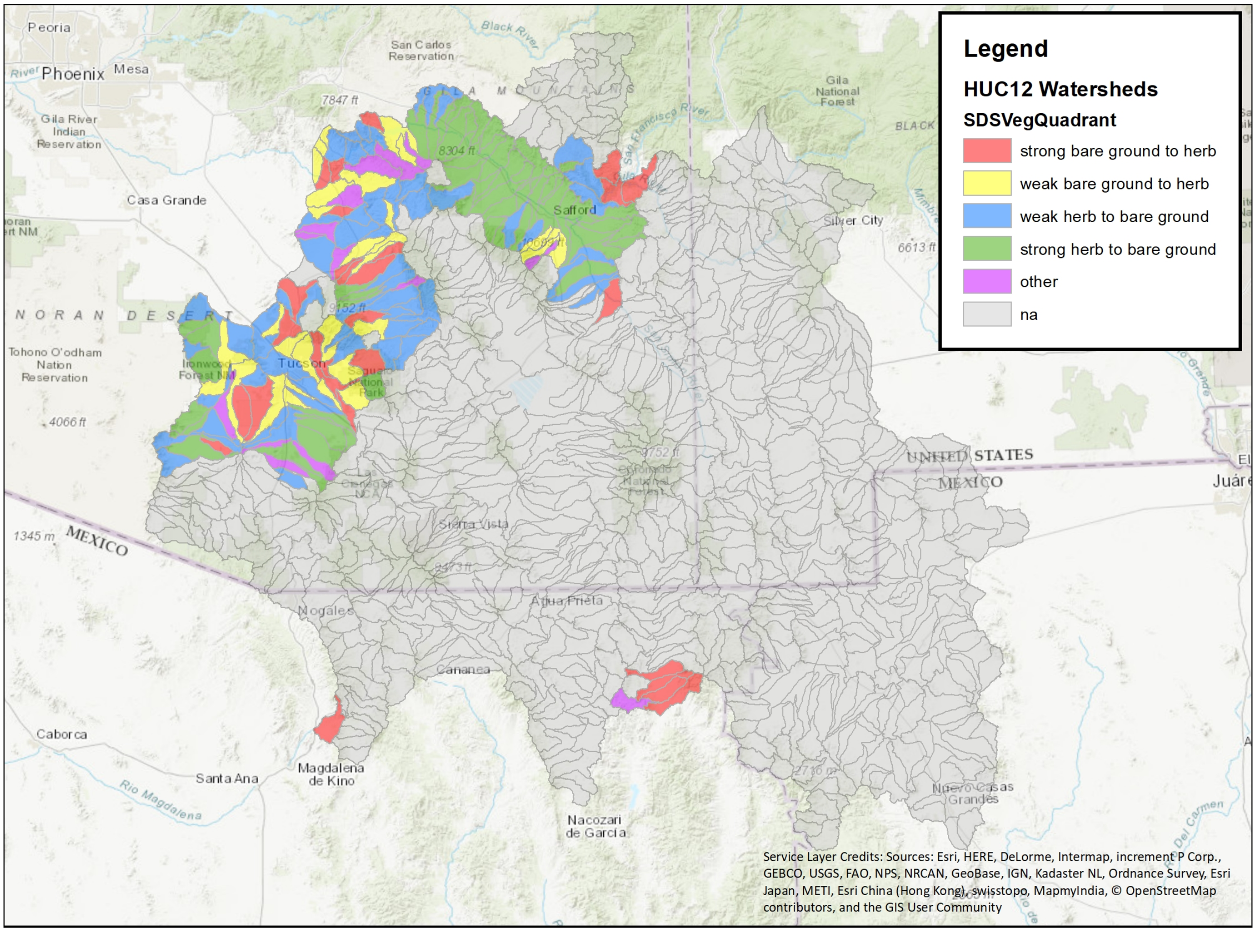

Figure 14. HUC12 watersheds, color coded by bare ground/herbaceous cover trend category within their Sonoran Desert Scrub.

Legend description:

- *Strong Herbaceous to Bare ground Trend:* watersheds with the 50% most negative SDSHerbTrend and 50% most positive SDSBGTrend
- *Strong Bare ground to Herbaceous Trend:* watersheds with the 50% most positive SDSHerbTrend and 50% most negative SDSBGTrend
- *Weak Herbaceous to Bare ground Trend:* watersheds with the 50% least negative SDSHerbTrend and 50% least positive SDSBGTrend
- *Weak Bare ground to Herbaceous Trend:* watersheds with the 50% least positive SDSHerbTrend and 50% least negative SDSBGTrend

Interpretation

We excluded 709 watersheds because they did not have any Sonoran desert scrub (SDS) mapped by Brown and Lowe (1981), or they had some mapped but were < 5% desert scrub according to the NALCMS (2010). This left 180 watersheds to analyze.

Overall, trends in bare ground and non-tree vegetation (herbaceous) cover were highly correlated

(Figure X, r^2=0.92). To be in the top 50% most negative SDSHerbTrend, watersheds had to have a value of < -14.5%; to be in the top 50% most positive SDSHerbTrend, watersheds had to have a value of > +12%. To be in the top 50% most negative SDSBGTrend, watersheds had to have a value of < -9.7%; to be in the top 50% most positive SDSBGTrend, watersheds had to have a value of > +18.3%. Twenty-seven watersheds were in the category of most concern - a strong bare ground to herbaceous trend (Figure 14). These watersheds have strong decreasing bare ground and strong increasing non-tree vegetation cover, highlighting them as potentially experiencing invasion of non-native herbaceous plants. The distribution of watersheds in each category is in Table 6.

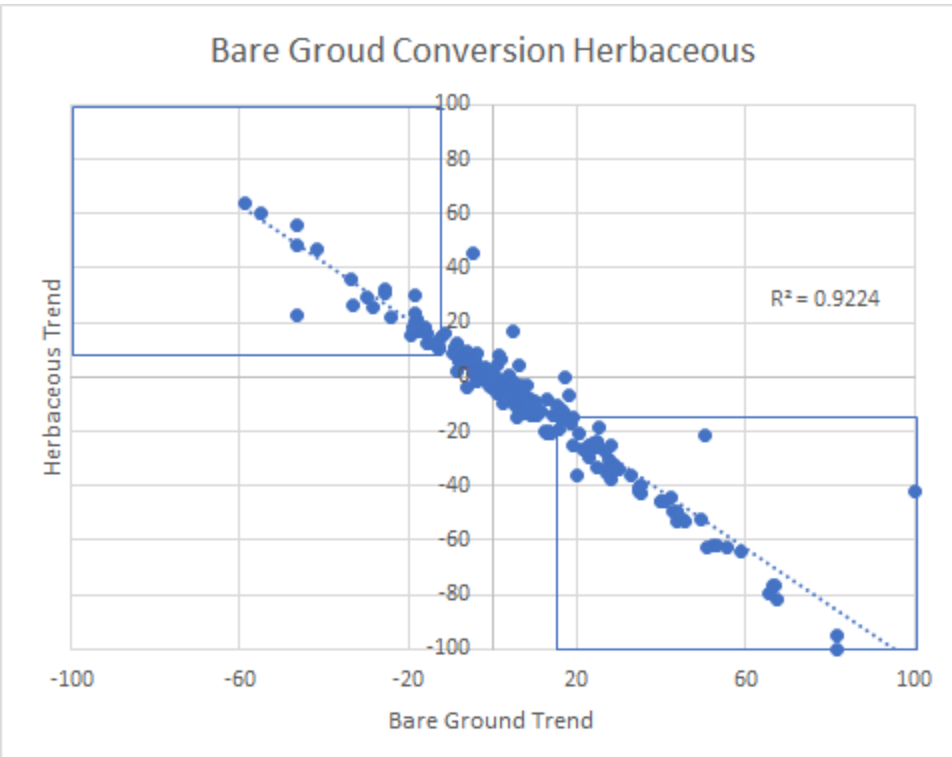

Figure 15.Correlation between trends in bare ground and non-tree vegetation (herbaceous) cover. Points in the upper left box represent watersheds with a strong bare ground to herbaceous trend, while points in the lower right box represent watersheds with a strong herbaceous to bare ground trend.

Table 9. Distribution of watersheds in herbaceous/bare ground trend categories.

Category	**Count**	**Percent**
Strong bare ground to herbaceous trend	27	15%
Weak bare ground to herbaceous trend	27	15%
Weak herbaceous to bare ground trend	58	32
Strong herbaceous to bare ground trend	54	30%
Other trend	14	8%

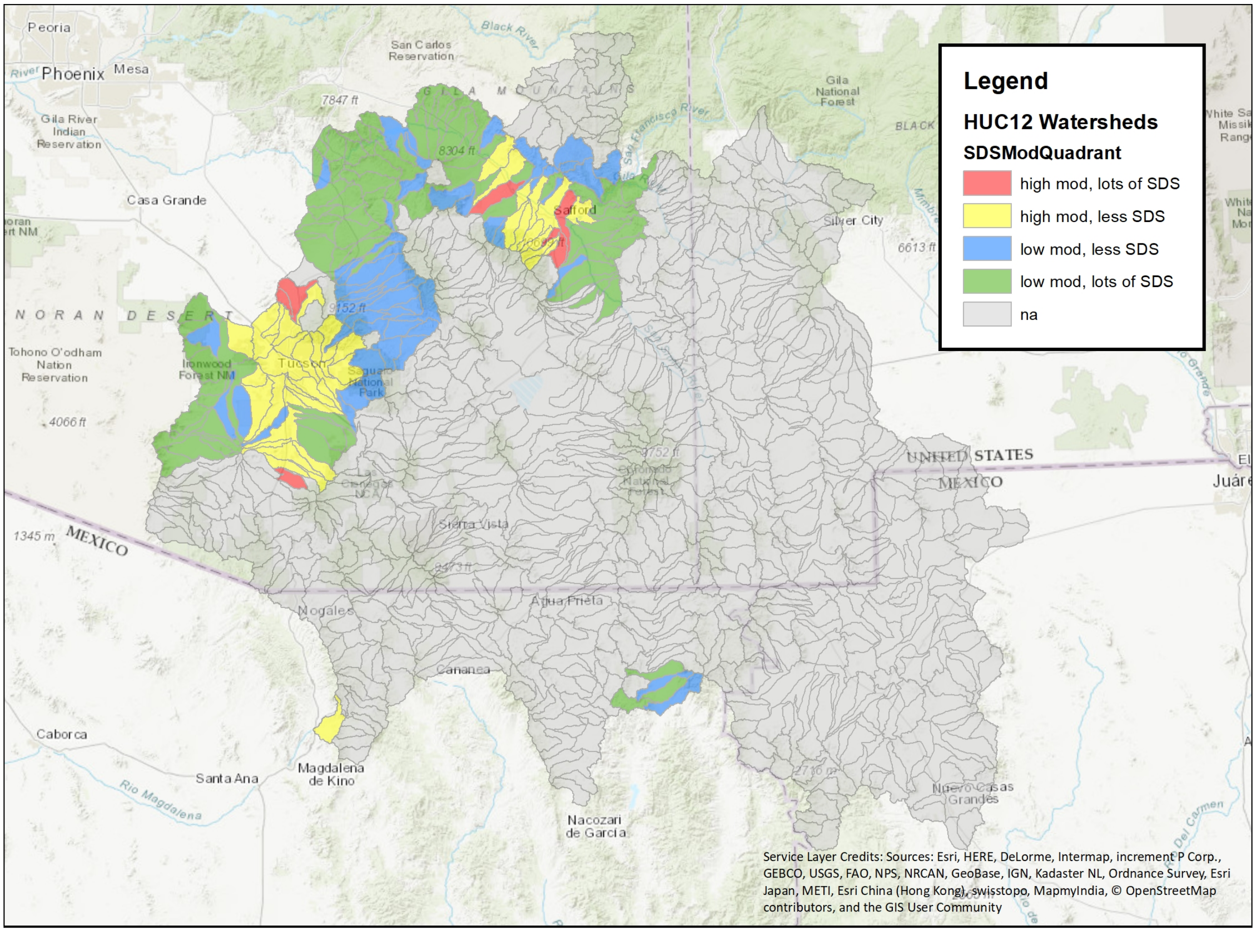

Figure 16. HUC12 watersheds, color coded by percent desert scrub/percent modified category within their Sonoran desert scrub.

Legend description:

- *Abundant SDS, High modification:* watersheds in the top 50% of PerSDS and top 25% of SDSMod
- *Less SDS, High modification:* watersheds in the bottom 50% of PerSDS and top 25% of SDSMod
- *Abundant SDS, Low modification:* watersheds in the top 50% of PerSDS and bottom 75% of SDSMod
- *Less SDS, Low modification:* watersheds in the bottom 50% of PerSDS and bottom 75% of SDSMod

Interpretation

To be in the top 50% of PerSDS, the percent cover of “tropical or sub-tropical shrubland" had to be >85.9%. To be in the top 25% of SDS_Mod, the percent cover of “urban or built-up" or “cropland” had to be >9%. Six watersheds in the Santa Cruz River and Gila River Valleys were in the category of most concern - high modification and abundant SDS (Figure 16). These watersheds have higher cover of Sonoran Desert Scrub, but also high levels of human development, potentially making them most at risk of large intact patches of SDS. Eighty-four watersheds had abundant SDS and low modification, primarily in the Lower Gila Valley, Lower San Pedro Valley, and Lower Avra Valley - these may be areas most likely to keep large amounts of SDS. The distribution of watersheds in each category is in Table 7.

Table 10. Distribution of watersheds in percent desertscrub/percent modified categories.

Category	Count	Percent (of analyzed)
Abundant SDS, high modification	6	3%
Less SDS, high modification	39	22%
Less SDS, low modification	51	28%
Abundant SDS, low modification	84	47%

HUC12 Watersheds - Water

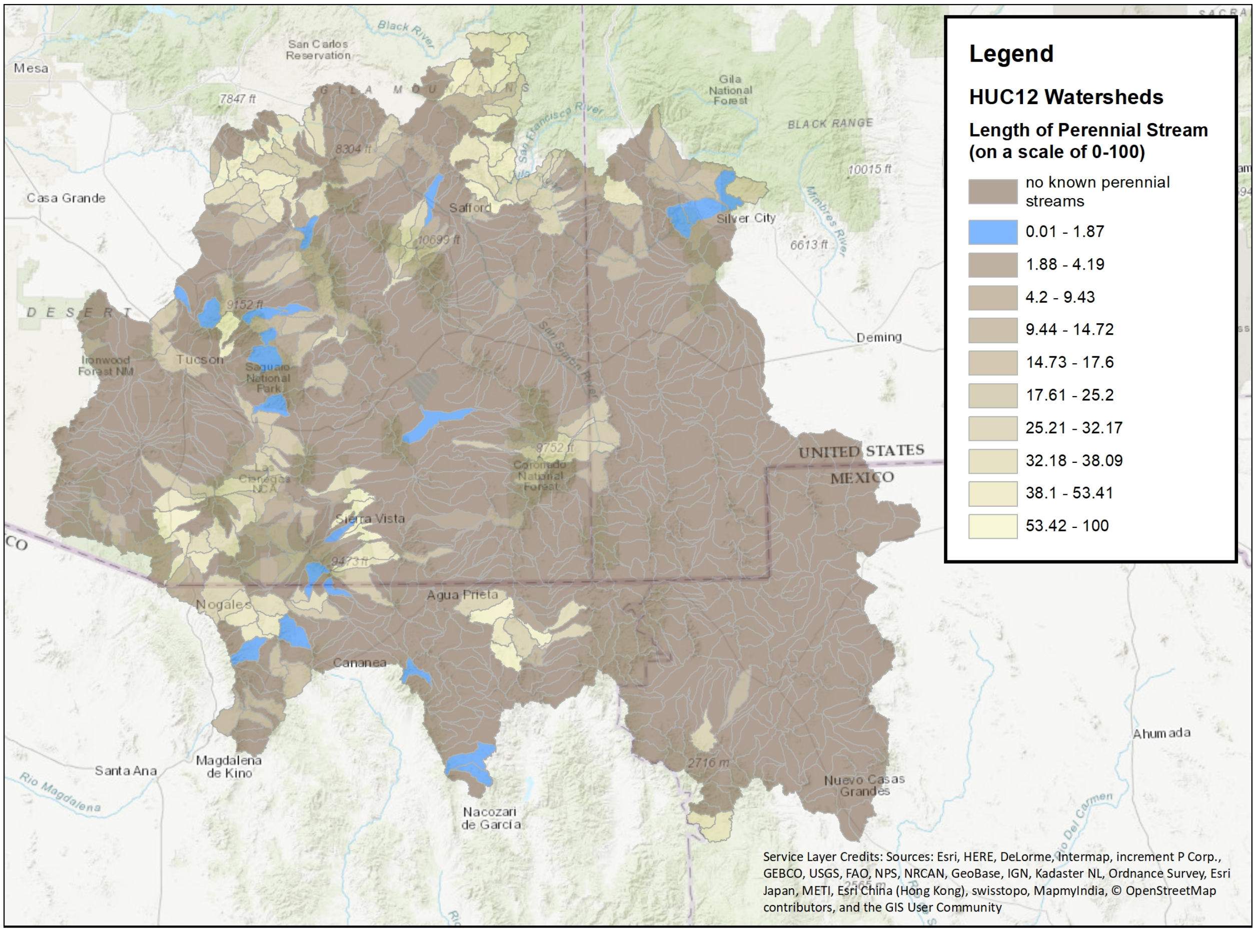

Figure 17. HUC12 watersheds, color coded by mapped perennial stream scarcity. Watersheds with some mapped water, and the highest scarcity (low Water_Scarce score) are highlighted in blue.

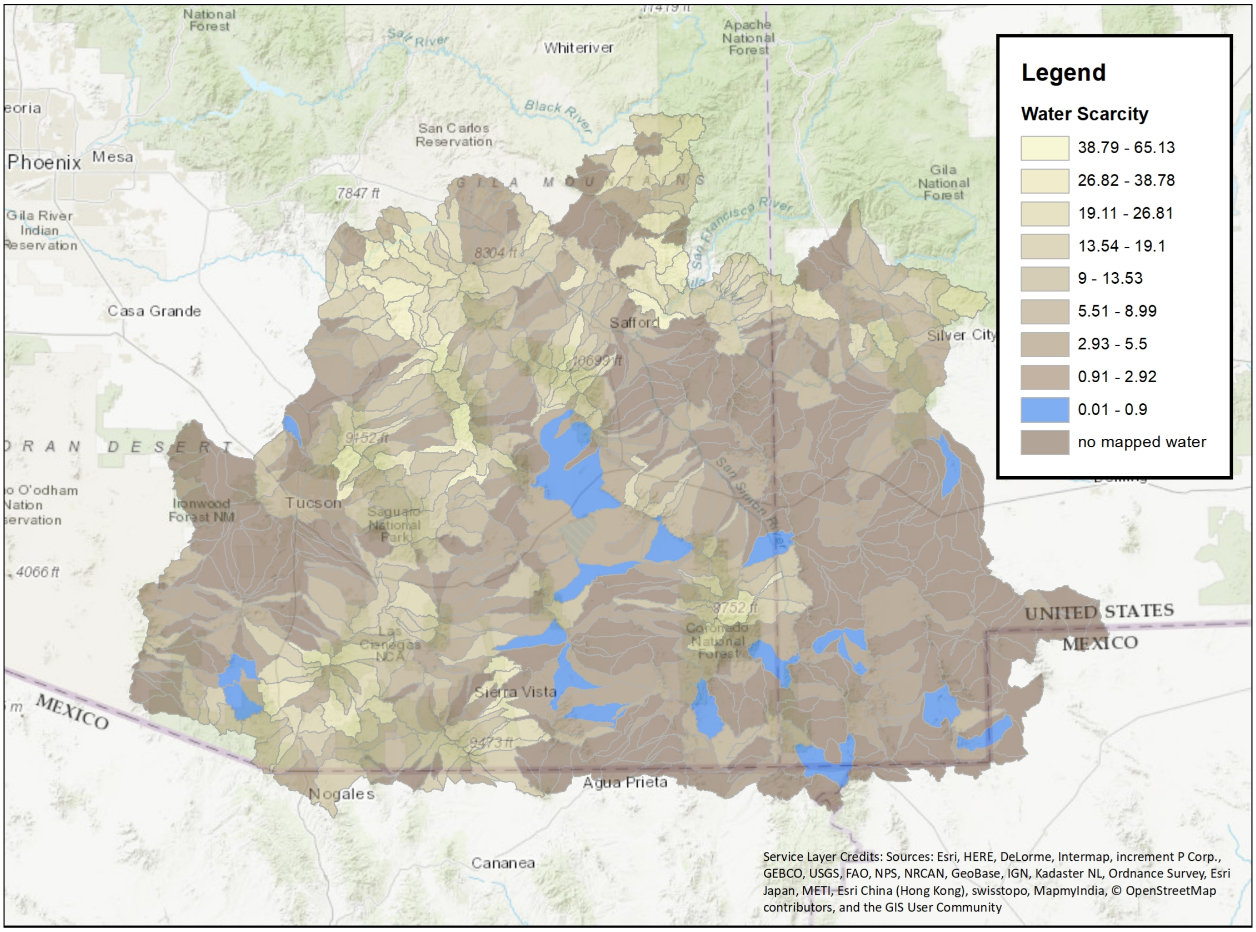

Figure 18. HUC12 watersheds, color coded by mapped surface water scarcity.

Legend description:
Water scarcity was calculated only for US watersheds, due to the lack of available data on springs in Mexico. Watersheds with some mapped water, and the highest scarcity (low Water_Scarce score) are highlighted in blue.

Interpretation

Out of 889 total watersheds, 442 (50%) did not have any mapped perennial streams or springs. However, this likely includes a substantial number of watersheds in Mexico that do in fact have springs - we simply don't have a mapped record of them. The 10% (45) of watersheds that have the least mapped water may be places where that water is particularly valuable to both the environment and humans. Water in those watersheds may be a priority for protection (Figure 17; Figure 18).

HUC12 Watersheds - Connectivity Areas

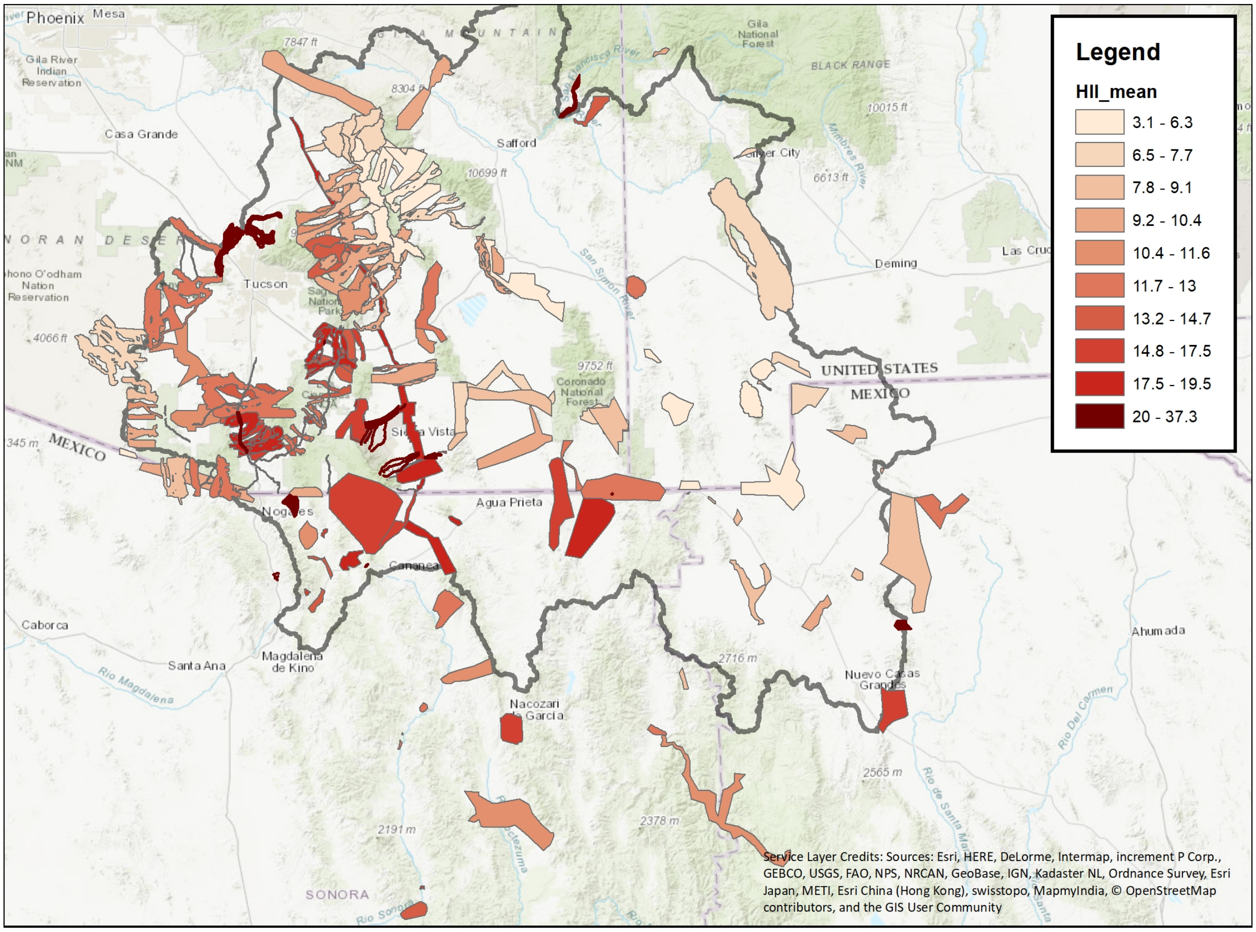

Figure 19. Connectivity Areas, color coded by degree of human influence (higher values = greater human influence).

Our final compiled shapefile contains 171 mapped Connectivity Areas, some of which overlap. The file contains 94 from the LCD process, 20 from Wilbor (2014), 19 from Atwood et al (2011), 14 from the AZ Missing Linkages Project, 9 from the AZGFD Pima County Wildlife Connectivity Assessment, 8 from Menke (2008), 7 from Hass (2001), and 3 from Dan Majka. The nineteen (10%) Connectivity Areas with the highest human influence are listed in Table X. Most (14) are in the San Pedro River and Santa Cruz River Valleys in the US, 4 are in Mexico, and 1 is in the Upper Gila River in Arizona (Figure 19).

Table 11. Connectivity Areas in the top 10% of Human Influence Index.

Name	HII mean
Slaughterhouse Cyn, Huachuca Cyn, Babocomari River	37.3
Rock Spring Canyon	32.6
Upper Santa Cruz River Corridor	30.7
Babocomari corridor	29.9

Name	HII mean
Santa Catalina Oracle X-Tortolita Hwy 77 break	29.7
Tucson to Tortolita	26.8
San Francisco River Corridor	25.5
Tortolita-Santa Catalina	24.6
Escondida to Capulin Hidalgo la Campana break	23.6
Blacktail Canyon	22.5
Tucson-Tortolita	22.2
Las Cienegas Fleming-Cienega Creek I-10 break	22.0
San Luis-Guadalupe Peloncillo Hwy 2 break	22.0
Ramsey Cyn and Carr Cyn	21.8
Miller Cyn	21.5
El Pinito to San Antonio Hwy break	20.6
San Pedro to Mule	20.2
Atascosa-Cibuta to El Pinito Hwy 15 break	20.0
Marquita-Elenita Hwy 2 break	20.0

Data Gaps and Future Improvements

We had to drop the greatest number of indicators due to lack of species-specific information (Table 3). While there are isolated pockets of information about particular plant and animal species, that information is very rarely available across the entire pilot area. In grassland and Sonoran Desert Scrub, this is a particular shortcoming. While we could infer something about the quality of grassland or invasion of herbaceous plants in SDS from vegetation structure information (tree, non-tree, and bare ground cover), not knowing plant species composition is a major hindrance to fully understanding the quality or condition of these environments. Similarly, managers need to understand how different bird guilds are doing in each ecosystem, as well as certain indicator species like pronghorn and mule deer, but we could not find comprehensive data on these species.

We dropped many stream indicators, and had originally planned to analyze riparian areas across the pilot area. However, stream data is sparse in this region, as is groundwater data. Riparian areas by their nature are a zone around streams. We would need to define polygons of riparian areas within which to analyze riparian or stream indicators. However, these have not been defined for the entire study area, and doing so would represent a substantial undertaking. Future iterations of this LCD may well be able to analyze riparian areas, as the Arizona Game and Fish

Department is currently in the process of defining riparian polygons across the entire state. However, the data is still missing for Mexico and New Mexico.

Another gap was yearly data on loss of ecosystems to development. The closest product we could find for both Mexico and the U.S. was the NALCMS, which is a newer product and only available for 2005 and 2010. Creating yearly data is possible but would require a separate effort.

There were two major gaps for data in Mexico that we weren't able to overcome - lack of information on fire and fuels, and spring locations. There is some burn severity information for fires in Mexico (Villareal and Poitras 2018), but it is only available through 2011 and does not classify dNBR into burn severity classes. For springs, we were not able to find data on locations, other than a limited number of surveys available in the SSI database (Ledbetter et al. 2020). Assuming the spring density in the Mexican portion of the pilot area is similar to the U.S., there are likely at least 750 springs in Mexico that we were not able to account for.

Lack of survey data for springs was another major gap. While over 300 springs have been surveyed in the US portion of the pilot area, and several dozen in Mexico, that represents fewer than 10% of all the springs in the region. Furthermore, surveys are not randomly distributed across the landscape. This meant that we could make few inferences about springs, so we limited the analysis to simple metrics like the density of springs (in the U.S. only). Groundwater data is even more patchy than spring data, and only available in the US.

Furthermore, our decision to use HUC12 watersheds as the primary unit of analysis limited the area which we could analyze in Mexico to a relatively small region near the border with the U.S., where watersheds were already delineated. Future iterations of this LCD should either delineate similarly sized watersheds in Mexico, or reanalyze the entire region using a different units of analysis, such as hexagons.

Similarly, future iterations should consider more careful definition of forest and grassland cores, and perhaps connectivity areas. For forest cores, we began with an existing dataset (Deyo et al. 2013), and added cores based on plant community and mountain ranges between the Mogollon Rim and the Sierra Madre Occidental. More detailed criteria should be created for how to define forest cores. Potential criteria could be change in slope, change in vegetation, change in ruggedness, etc. Should cores be based on mountain ranges, or simply blocks of forest habitat? Grassland cores would benefit from a similar examination. This would improve comparisons of different core areas and make tracking changes over time more meaningful.

Other suggestions for future versions include adding data on vegetation cover from prior to 2000, as far back as it is available, and changing the method for understanding Summer NDVI values. The current calculation is the average value in each watershed for the summer monsoon season (July, August, and September). It may be more meaningful to subtract the maximum NDVI values for this period from the NDVI values in June, the driest time of year. This would allow us to understand the relative green-up between different areas of the landscape.

Chapter 3—Management Challenges and Opportunities

Defining the challenges related to climate change adaptation and the strategies that can be used to address them has been a central activity of the Madrean LCD. Prior to being chosen as a pilot area for the Desert LCC, partners who participated in the 2015 Pilot Area Workshop discussed a general list of adaptation strategies presented by the Desert LCC (strategies that were Desert LCC-wide and not specific to the Madrean area). After the Madrean LCD was chosen as a pilot area, partners helped identify the stressors local ecosystems experience related to climate change by participating in a survey conducted by the Desert LCC Critical Management Team for Landscape Monitoring.

At the *Madrean Watersheds Conservation Design Workshop* (Appendix 1c) participants reviewed results from the stressors survey including the list of stressors most relevant in the region, and described ways in which the stressors would specifically impact Madrean focal resources (grasslands, springs, streams/riparian, Sonoran desert-scrub, Madrean evergreen woodland). They also conducted adaptation action planning by identifying current work to adapt to climate change, immediate steps for furthering that work, and general management strategies for climate change adaptation. Participants also listed critical management questions for the region, and those included questions on how to adapt to climate change.

We compiled this information from partners about: the adaptation actions they are implementing to reduce vulnerability to management challenges; new adaptation strategies and actions they could potentially implement; and how the partnership might support this work.

Management Challenges

Management questions and adaptation strategies were summarized into synthesized list of the highest priority management challenges for climate adaptation that was reviewed and discussed by the Coordinating Team. The following management challenges were identified:

- Altered fire regimes: Changes in extent, frequency, severity, and seasonality
- Altered streamflow: Dams, diversions, ditches
- Altered springflow: Modifications
- Decreasing water availability
- Groundwater pumping
- Temperature extremes
- Invasive species
- Habitat loss and fragmentation
- Grazing pressures
- Erosion and altered geomorphology
- Worsening water quality

- Uncoupling of phenological relationships
- Changes in community composition
- Coordination, collaboration, and communication
- Impacts on culture, well-being, and livelihoods

Adaptation Planning

Having identified key challenges in the region, the Madrean LCD built on the discussions about localized adaptation efforts by formalizing region-wide adaptation strategies directly correlated to the list of management challenges. We hosted a webinar for all LCD partners to hear about and discuss the connections between management challenges and adaptation strategies. This webinar provided final input for the existing list of climate adaptation strategies in the Madrean LCD area.

Case Studies

In parallel with the work on management challenges and adaptation strategies, partners of the Madrean LCD also contributed case studies to the Collaborative Climate Adaptation Strategies Toolbox (CCAST). CCAST is an online, open-access library of case studies that provides real-life examples and contacts for managing the diverse array of issues related to climate change and its associated stressors. The stories of Madrean LCD partners are now available for others across the Southwest to learn from.

The Madrean LCD worked with the other DLCC pilots (the Eastern Mojave and the Dos Rios LCDs) to design an interactive website that aligns climate-related challenges, strategies suggested by LCD participants, and related case studies. The 246 adaptation strategies for the Madrean LCD region are stored and available for viewing in this online application, which is called Awesome Tables.

Connecting Management Challenges and Adaptation Actions

We developed a catalog of adaptation actions using input provided by LCD partners between from 2015 through 2018. To do this, we reviewed all documents (meeting notes, workshop summaries, project reports, partner exercises, and planning documents) related to LCD from this time period. We added actions to the catalog based on specific comments about adaptation actions provided by partners. In instances where partner input was provided in Spanish, we had the actions translated into English. The actions were then either added to the catalog if unique, or incorporated into similar English entries. We compiled the list of adaptation actions in a spreadsheet using a unique index number for each one. We then edited the actions for clarity of language, where needed, and to combine actions that were similar. In some cases, we removed actions from the list because there was not sufficient detail provided in the source document to make the action actionable.

We identified and cataloged 3 different types of actions: management strategies, monitoring needs, and research needs. For all three types, we categorized each action based on the following themes: the LCD goal the action would support, they type of approach the action represents, and the ecosystem of interest (the ecosystem that was being discussed when the action was mentioned). For management strategies, we also indicated which high-priority management strategies the action would help address.

We linked actions with existing case studies that are relevant. To do this, we reviewed all existing case studies available in the Collaboration Conservation Adaptation Strategy Toolbox (CCAST) as of May 2019 and compared them with the list of actions. Where a case study provides insight into how an action might be carried out, we provided the case study links and title. There are some actions without any links to case studies, and some that have multiple links to case studies.

We compiled this information into Awesome Tables to build a user-friendly viewer that allows users to determine which data to view. We created two tables with tentative titles: one for management strategies (Management Strategies for the Madrean Region), and one for research and monitoring needs (Madrean Region Research and Monitoring Needs). The decision to split the data into two parts was made to simplify the user's experience in the Awesome Tables; it allows for fewer buttons and fewer items to look through for people who are primarily interested in either management or research.

Orientation to the Tables

The top section of the table viewer shows a series of rectangular text search fields and buttons that produce dropdown menus where users can filter the actions according to which of the categories above they want to find. The bottom part of the Awesome table page automatically shows a table of actions that reflects the criteria supplied by the user. Where possible, hyperlinks to related case studies are provided in the row of the action

In the top section, there is one text search box for the index number of an action, and another for searching the text of the listed actions. The rest of the rectangles are buttons that produce dropdown menus where users can select a "y" (yes) or "n" (no) to indicate if they want results related to that topic. After selecting one criteria, each additional criteria is added in addition to other(s). For example, selecting "y" for "Grasslands" and "Riparian areas" will return results that apply to both only, not one or the other. In other words, if an action is related to "Grasslands" but isn't also found under "Riparian areas," it will not show up in the results..

Recommendations for Use

These resources are a record of the input collected since 2015. They represent data collected over four years of discussions about high-priority management challenges, what people are doing about them, ideas for projects that this partnership could support, and what research and data could help with making management decisions.

As the partnership moves forward with whatever kind of structure and function it takes into the future, this information can be used to jumpstart it. The actions presented here reflect may different kinds of approaches to management challenges, ranging from from ecological challenges to barriers to effective communication, collaboration, and economic stability in the region. The ideas presented in these actions could provide a starting point for moving forward.

Furthermore, the resources have been designed to allow for refinement of the actions, and can continually be updated with new case studies in CCAST. Actions could be refined particularly if they are selected for collective effort, at which point the resource also served to inform CCAST staff of what kinds of case studies would be most helpful for the LCD effort. Since these Tables are easily edited, they can evolve with the partnership. It could be a valuable exercise to go through some of the research and monitoring needs with partners and figure out which are needs for new analyses, and which ones are more like communication needs, meaning the information is out there but it's not widely known about or not easily accessed.

One nice feature of the Awesome tables is that users can generate a unique url for a particular set of search criteria they have entered into the table. This could be useful for coordinators looking to stimulate conversation about a particular set of topics. For example, instead of leading everyone on the call through entering the criteria to review a subset of actions, coordinators can just send a link to partners with the table pre-filtered.

For people within or outside of the partnership, these tables are an alternative interface for accessing case studies in CCAST, and one specifically oriented toward issues in the Madrean region. It also provides a snapshot of many on-the-ground projects in the Madrean LCD region. In their current form, the actions are focused on players and places involved with the Madrean LCD, but with some trimming down of actions, it could be developed as a resource for anyone in the greater Southwest region to inspire creative thinking about how to address management challenges.

With the open-access Awesome Table that integrates management challenges, adaptation strategies, and case studies directly contributed by partners of the Madrean LCD, there is now a resource to support adaptation to a broad array of challenges posed by climate change. This product is a result of iterative discussions that took place at workshops, meetings, calls, and webinars, and the process led to a product that offers realistic solutions for the most pressing climate adaptation issues in the region. It is hoped that all Madrean partners, from managers to researchers to non-profits to conservation organizations, will benefit from the online interface.

Climate Change – Vulnerability and Potential Future Scenarios

Vulnerability Assessments

Vulnerability assessments (VAs) are a common input into conservation planning for adaptation to climate change and other management challenges. Many landscape-scale efforts initiate new VAs for their own purposes, and therefore there is a significant body of work assessing vulnerability of species, ecosystems, and ecosystem services. We worked with partners, Desert LCC staff and the Madrean Coordinating Team to carefully considered this approach and decided to invest time and resources into using already available information to conduct in-person collaborative adaptation planning.

Rather than develop new VAs and potentially replicate existing work, or generate VAs that may not prove useful later in the multi-year LCD process, the LCD team moved forward with creating an annotated bibliography of VAs with areas of interest that overlap the Madrean LCD region, and a standard bibliography of citations on research done on the usefulness of VAs, ways they are used, methods for their development, and examples relevant to Madrean LCD. Nearly 40 different vulnerability assessments have been completed in the Madrean LCD area that relate to ecosystems, flora and fauna of interest, ecosystem services like water availability and human livelihoods that depend on ecosystem services, and the interaction of ecosystems and human development via wildfire.

Methods

We searched VAs that were freely available online via several websites of organizations we knew had produced or compiled VAs. Table 12 shows the websites we searched with search terms provided in parentheses.

Table 12. Location available online vulnerability assessments and where to access them.

Organization	**URL**	**Search Terms**	**Notes**
Desert Landscape Conservation Center	https://desertlcc.org	"vulnerability"	
US Forest Service	https://fs.usda.gov/tresearch	"vulnerability assessment"	Searched for publish dates between 1995-2019
Southwest Climate Adaptation Science Center	https://www.swcasc.arizona.edu	"vulnerability" and "vulnerable"	
South Central Climate Adaptation Science Center	https://southcentralclimate.org	n/a	Looked through projects presented in a story map on the website
Climate Registry for the Assessment of Vulnerability	https://crave.cakex.org	"Arizona" OR "Mexico" OR "New Mexico"	
NatureServe	https://natureserve.org	"Vulnerability" and "vulnerable"	Search done for publications with "vulnerability" in the title

All website searches occurred during January and February of 2019, except for NatureServe, which was searched again in August 2019 when it came to our attention that new resources were available there. We also reviewed the bibliographies of two works that we thought might contain additional papers of interest (Friggens et al. 2014; Madrean REA). Additional VA's were provided by partners. Only resources that are freely available online are included above.

To facilitate use of these existing vulnerability assessments, we created an annotated bibliography (Appendix 3c, available for download in a searchable excel format at skyislandalliance.org/madreanlcd)

Recommended Use
These bibliography is intended to allow partners to assess the current scope of existing VAs for the region so as to avoid allocating resources unnecessarily to developing new VAs, and to provide easy access to information about how they are used. By using these resources, partners can have informed and focused discussions about the role VAs should play in future conservation planning.

Scenario Planning

Scenario planning is a comprehensive process that involves the development plausible future scenarios, consideration of their impacts, and identification of the implications for integrated conservation-adaptation action. Scenario planning was led by the Southwest Climate Adaptation Science Center in partnership with the Desert LCC, Madrean LCD staff and Madrean Coordinating Team.

Scaffolding is a new term used to describe baseline data sets that comprise a suite of physical and biological factors common to each area of interest, or pilot area, within a given geography. These components are the "scaffolding" or framework for customized socio-economic data sets unique to each area of interest. We utilized a participatory approach that utilized a scaffolding of scenarios for climate, vegetation, and ecosystem processes. Scenario planning was designed to support managers' thinking about how climate changes now and in the future might affect focal resources, stressors, and their ability to reach their conservation goals. Input was gathered from partners on *what* to assess (e.g. climate, vegetation, development, etc.) and *which* projections to include (e.g. which climate projection(s) to select). Scenario planning products and tools were used to help partners:

- Better understand the impacts of future scenarios on socio-economic and conservation values
- Identify how shared values would be impacted under different probable future scenarios and which management strategies have the highest potential for being effective to maintain stakeholder values, and reduce risk under all probable future scenarios
- Help motivate the development of partnerships to support on-the-ground implementation of integrated conservation-adaptation strategies.

The following components were considered for development during scenario planning:

Climate scaffolding (expert-based)
- Downscaled model projections
- Relevant derived variables (T-min, Tmax, ET, soil moisture, GGD, heat index)
- Hydrology-stream flow models, erosion, D. Isack work
- Point location T&P trends (U-ID dashboard)

Vegetation scaffolding (expert-based)
- DGVMs (Cons Bio Institute-D. Bachelet)
- SppDistModels (Forest Futures)
- Phenology (USA NPN)
- Physiological drought/moisture stress
- Literature review

Ecosystem processes (place/expert-based)

- Fire (prescribed, wildfire, severity & extent)
- Insect outbreak
- Forest mortality and die-off
- Conversion
- Regeneration

Stakeholder Priorities (participation-based; from existing materials & surveys)

- Biodiversity conservation (springs, grasslands, streams-riparian)
- Socio-ecological/ecosystem service-oriented
- Examples:
    - Optimize watershed benefits (water & habitat) for humans/ecosystems/wildlife
    - Maintain soil function and reduce erosion
    - Increase human connections to place
    - Support working landscapes (grazing, ranching) for ecological benefits (water & habitat)
    - Recreation-tourism
    - Linkages to wine growers
- Identified goals & objectives
- Related impacts and vulnerabilities
- Implications of climate change for priorities

The eco/hydrologic scaffolding along with notes and examples for use is available in Appendix 3b.

Following initial review of information already collected from partners the scenario planning team identified the biggest remaining unknowns pertaining to top priority stressors (identified at Sept 2016 workshop & Indicators Workshop) for each focal ecosystem via web discussions with land and water managers & academics.

The following two scenarios were co-developed around unknowns based on leading possible futures according to science and manager observations, and considering human responses to stressors. They are in a narrative format:

- A Wildfire in a Warmer World in 2025
- Megadisturbance & Rapid Ecosystem Transformation, 2040

See Appendix 3a for the full narratives. The Madrean Coordinating Team reviewed these scenarios, discussed how they might be made more useful to planning, and provided feedback on additional information they'd like to supporting planning. Managers used these scenarios to consider potential future management actions starting with current management protocol.

Socioeconomic Indicators

Partners in the Madrean LCD recognize that human systems and ecosystems are inextricably linked, and that improvements in conservation can lead to improved human well-being, and vice versa. While partners have moved forward with selecting ecological indicators to monitor the success of the LCD effort, much discussion has been had about the importance of also considering human health, sustainability, and local economies. For the purposes of informing future such discussions, the LCD core team compiled a bibliography of approaches for incorporating socio-economic factors into conservation planning (see Appendix 3d) and a list of potential socio-ecological/economic indicators for the Madrean area (see Appendix 3e).

The list of potential indicators was informed by input from Madrean partners at meetings and workshops, examples from other large landscape conservation efforts, and an online literature review. As a whole, the sources contain many more potential indicators that are not in the list. Instead of attempting to create an exhaustive list of potential indicators, this list is intended to show the large diversity and scope of options when considering the selection of socio-ecological/economic indicators.

The indicators are compiled in a spreadsheet (Appendix 3c). Each indicator, includes a citation, or in the case of LCD notes a description of the source document, and a link to the document.

Chapter 4. Lessons Learned and Recommendations for Future Work

Lessons Learned

Working with a wide variety of partners during this multi-year collaborative conservation design effort has led to a number of important lessons and recommendations for future. We present here a few of the key challenges and lessons, and recommendations for future use of geospatial tools and collaboration opportunities moving forward in the Madrean area.

Collaboration with partners in Mexico - Genuine collaboration with partners in Mexico was a recognized challenge throughout the Madrean LCD effort. Communication between Mexican and U.S. partners was often challenging from a logistical standpoint (U.S. conference call numbers were not accessible by Mexican partners without fees; Skype and other video conferencing often suffered from poor connectivity). Interpretation between English and Spanish on Coordinating Team calls made calls lengthy and required additional staff. Limited support for travel between both countries severely limited in-person engagement opportunities. In terms of spatial data, U.S. partners had difficulty obtaining parallel datasets for Mexico, making analysis of certain factors including fire and fuels, and spring locations impossible. In order to achieve real collaboration across the US-Mexico border, projects should recognize this challenge up-front and build in resources and time to support communication, travel and data sharing between international partners.

Discrepancies in scale between planning and implementing - The scale of the Madrean LCD presented a challenge from the outset. There are real differences between the scale at which we need to plan in order to address large-landscape challenges, and the scale at which projects can actually be implemented. It is often difficult to translate large-scale (lower resolution) data into tools that can inform spatially explicit projects by willing partners. The team saw that catalyzing action through smaller, place-based collaboration was the most effective way to engage local partners. However, focusing only on a smaller scale, we lose the context of the landscape and the ability to understand how actions contribute to larger strategies. We are left with the question: what is large enough to be landscape-scale, and small enough to support action?

Dissolution of the Desert Landscape Conservation Cooperative - In addition, significant challenges were posed by the slow dismantling of the Desert LCC. For large portions of the project timeline, there was uncertainty about the future of the Desert LCC, which made planning and communicating with partners difficult. A large-scale collaborative effort is dependent upon building relationships and trust, and the assurance of consistent support. It takes time to develop shared goals, and even longer to align for action. When the underpinning structure and support for the effort is in question, the requisite components of successful collaboration are on unsure footing. It is to the credit of the dedicated partners in the Madrean region that the effort was able to continue in spite of this uncertainty.

Recommendations for Future Work

Collaboration to Implement the Madrean LCD

Looking ahead, there is an energetic and engaged community of partners, and a number of priority issues identified through this work which will demand continued and strengthened collaboration. Some topics requiring ongoing collaboration that could benefit from working groups or partners leading are listed below. The concepts of building a collaborative structure and strengthening bi-national relationships would be inherent in acting on these topics.

Implementing strategies to enhance wildlife connectivity - The map of connectivity areas has provided an excellent starting point for regional planning for connectivity. Opportunities for enhancing connectivity could include processing land purchases or easements, constructing wildlife overpasses or underpasses, improving fencing, planning for open space through zoning etc., or coordinating monitoring efforts. Convening partners working across jurisdictions, as well as at smaller local scales, to plan connectivity actions could greatly benefit the wildlife and overall resilience of the Madrean region. In the Lower San Pedro Watershed, a collaborative is utilizing the connectivity products to begin prioritizing conservation actions in wildlife corridors. In the Altar Valley Watershed, partners are using the information gathered for the connectivity map in a watershed-wide conservation action plan

Supporting an effort to coordinate wildlife camera monitoring and data - Many organizations in both the US and Mexico portions of the Madrean region monitor wildlife through game cameras, and partners have expressed interest in creating a collaborative website for storing and analyzing photos. Having a single database for many photos would not only provide more regional-scale information about wildlife populations and the effects of management actions, but it would also help organizations pool monitoring resources and focus them more efficiently.

Working to mitigate invasive species impacts - Invasive species in every biotic community of the Madrean have been emphasized by partners as a high-priority issue. It is difficult for managers and researchers to stay abreast of invasive species populations and locations because of their high rates of spread. Organizations could benefit from more immediate access to data, efforts, information, and funding sources in their efforts to mitigate and remove invasive species. Supporting closer coordination among managers and practitioners addressing invasive species issues would help Madrean partners manage invasives more proactively and effectively through mitigation rather than removal; collaborative groups exist that could be brought together at a regional scale.

Cultivate place-based connections and stewardship - The Madrean LCD has helped increase the sense of place for the region, and partners have clearly expressed the desire to improve communications about the unique and important resources of the Madrean region. Many creative ideas for storytelling, using social media, and integrating standardized language in existing communications have been suggested. Convening partners who have shared those ideas may result in a focused effort to increase the sense of place of all people living in working in, and visiting the region. The increased connections to the Madrean landscape may result in greater stewardship of the land and respect for the diverse human cultures existing here.

Convening of watershed organizations - Multiple collaborative efforts in the Madrean region are focused at the watershed scale, and these groups encounter similar issues to one another. Efforts exist to connect watershed groups across the region, and the Madrean LCD effort has shed light on the issues that pervade watersheds and jurisdictions. Some issues include monitoring, utilizing geospatial data and tools, and enhancing wildlife corridors.

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