Fire and Water: Assessing Springs Ecosystems and Adapting Management to Respond to Climate Change

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This project would not have been possible without the dedication and enthusiasm of **122** Sky Island Alliance volunteers that spent their weekends in the field driving rough roads and hiking steep terrain without trails. These volunteers contributed 2,357 hours to this project.

Executive Summary

Introduction

Sky Island Alliance is a non-governmental organization that works to protect and restore the rich natural heritage of native species and habitats in the Sky Island Region. We work with volunteers, scientists, land-owners, public officials, and government agencies to establish protected areas, restore healthy landscapes, and promote public appreciation of the region's unique biological diversity.

Springs are keystone ecosystems in the Sky Island Region, exert disproportionate influence on surrounding landscapes, and are known to be biodiversity hotspots. Although they are abundant in this arid region, they are poorly documented and little studied. Changing fire regimes – particularly, increased size of high-severity burn patches and more intense precipitation events post-fire – are directly affecting springs ecosystems, yet these effects are poorly understood. Finally, many springs suffer from extensive human modification. Lack of information on their location, management context, and biological, hydrological, and ecological characteristics hinders effective stewardship of these resources.

This project builds on a previous spring inventory and management project supported by the Desert LCC (Misztal et. al. 2013). This project addressed outstanding inventory needs and key management questions for spring ecosystems in the Sky Island Region of southeastern Arizona located at the heart of the Desert Landscape Conservation Cooperative (Desert LCC) geography. Newly collected baseline information on previously unassessed springs in the Upper Santa Cruz River Basin and other areas of high priority is now available through Springs Online, an online springs and springs-dependent species database, and an ArcGIS spatial query tool. Springs stewards in the Desert LCC geography are becoming trained in use of the database. We employed a combination of expert and citizen science inventories and assessments to collect critical baseline information on known springs in areas of interest and priority in the region, including areas affected by recent fires. This volunteer-driven inventory program is a model for monitoring climate sensitive resources with limited resources.

Additionally, we developed and implemented methodologies for climate-savvy monitoring at a set of high-priority springs through the Adopt-a-Spring program, and worked closely with the Springs Stewardship Institute to develop guidance and best management practices for protecting and restoring springs through publication of an Arizona Springs Restoration Handbook. We worked with managers to incorporate newly-collected data and guidance on monitoring and restoration of springs into planning and project implementation to reduce vulnerability to climate change.

Methods

To enhance the management and restoration of springs in the Sky Island Region of the Desert LCC, we collected baseline data on the biology, ecology, geomorphology, and management status of springs for which this information does not currently exist; we also catalogued the effects of fuel treatments and wildfire in areas of high priority. Our primary study area was the Upper Santa Cruz River Basin hydrogeologic area, within which we identified 274 springs using existing maps, expert input, and survey data. Within the Upper Santa Cruz River Basin, we inventoried springs and conducted assessments to characterize ecological integrity in relation to human influences. We used geospatially-stratified random sampling to identify a subset of 50 springs for targeted assessment. This allowed us to draw conclusions about springs ecosystems and integrity at a regional level. We visited a total of 84 springs, 41 of which were part of the random-sample study design and 71 of which we were able to locate. We also inventoried all previously unmapped springs that we discovered through field surveys. To catalogue effects of recent fires on springs' ecology, we inventoried and assessed 25 springs in the Chiricahua and Pinaleño Mountain Ranges that were in areas that recently experienced fire or were slated for fuels treatments.

We conducted spring inventories and assessments with teams that consisted of at least one Sky Island Alliance staff person trained in springs inventory protocols (or a suitable professional partner substitute) and one or more volunteers formally trained in assessment protocols.

Springs inventories and assessments were part of a larger Sky Island Region project focused on improving the understanding, management, and restoration of springs. Other project components included extensive coordination with resource managers, training land and resource managers in use of Springs Online (the inventory database), development of an Adopt-a-Spring monitoring program, development of an Arizona Springs Restoration Handbook, and site-specific management planning for springs. Here we present a description of the full project methodology, project outcomes, and analysis of the results of springs inventories and assessments. Appendix B and C includes full reports on the 71 springs located during the project.

Results

Springs Types: We detected 8 types of springs with the following order of abundance (Figure 13):

Rheocrene >> Hillslope > Anthropogenic > Hanging Garden; Helocrene > Cave; Hypocrene; Limnocrene

Five springs were classified as primarily or secondarily anthropogenic with another primary or secondary type because they were modified so extensively that their sphere of discharge was altered. Of the 32 randomly sampled springs successfully inventoried, 19 were developed for a development rate of 59% across the study area. Developments at springs primarily included spring boxes, constructed dams, piping to holding tanks or cattle drinkers, and accompanying devices like floats.

Springs Habitat Area: Spring site area calculated from site sketch maps ranged from a low of 0.1 m^2 at Brinkley Spring to a high of 100,000 m^2 at Agua Caliente Spring, with an average spring area of 5,140 m^2 (s = 19,625). Most springs were between 10 and 100 m^2, with a median spring area of only 80 m^2. The total area encompassed by springs surveyed in the Upper Santa Cruz River study area was 153,933 m^2 or 0.0024% of the (6,319,761,736 m^2) study site.

Elevation: Elevation at spring sites ranged from a low of 822 meters at Agua Caliente Spring to a high of 2,742 meters at Cascade Spring near the peak of Mount Lemmon in the Santa Catalinas, with an average elevation of 1,888 meters.

Isolation: The distance from springs inventoried to the next nearest spring site ranged from a low of 132 meters at Rock Spring, to a high of 4,431 meters at Agua Caliente Spring with an average distance to nearest spring of 967 meters. Most springs were within 1,500m of another spring, but a small number were quite isolated

Flow: For the springs with sufficient flow present to measure, the flow rate ranged from a high of 0.2 L/s at Bellows Spring to a low of 0.003 L/s at Ruelas Spring. The average flow rate for the study area was 0.06 L/s (n=12).

Water Quality: Field specific conductance ranged from a high of 1,086 ųS/cm at Crescent Spring to a low of 42 ųS/cm at Cascade Spring with an average of 347 ųS/cm (n=18, *s*=343).

PH ranged from a low of 6.4 at Ranger Station Unnamed spring, an undeveloped high-elevation spring, to a high of 8.6 at Red Spring, an undeveloped mid-elevation rheocrene spring, with an average of 7.3 (n=19, *s*=0.56).

Water temperature ranged from a low of 5.95 C at Bellows Spring, an undeveloped high-elevation spring, to a high of 27.9 C at Red Spring, an undeveloped mid-elevation rheocrene spring, with an average of 7.3 (n=19, *s*=0.56).

Flora and Fauna: We collected 808 plant records at surveyed springs, including 231 species identified to the species level, 85 species identified to the genus level, and 4 species identified to a higher taxonomic level. Of these, 21 species were identified as invasive. We collected invertebrate observations at 24 springs and recorded 21 orders of invertebrates. We collected vertebrate observations at 29 springs. We observed 102 species of vertebrates: 12 species of reptiles and amphibians, including Chiricahua leopard frog; 15 mammal species, 1 fish species, the invasive mosquito fish; and 74 bird species. The most commonly recorded vertebrates were:

Deer > Yellow-eyed Junco > House Wren, Western Tanager > American Robin, Spotted Towhee

Fire Effects: We conducted inventories and assessments at 24 springs in the Pinaleño and Chiricahua Mountains on Coronado National Forest land within burned areas or the PERP. The average SEAP fire influence condition score for fire affected springs was 3.5; when unlocatable springs were included in the average with a score of 0 (fire influence has eliminated the spring), the average was only 3 (moderate negative influence). Different spring types had about the same average condition as each other. As would be expected, springs that experienced higher burn severity tended to have lower condition scores, with the burn severity in the 50 m radius having a stronger correlation than in the 250 m radius.

Management Considerations

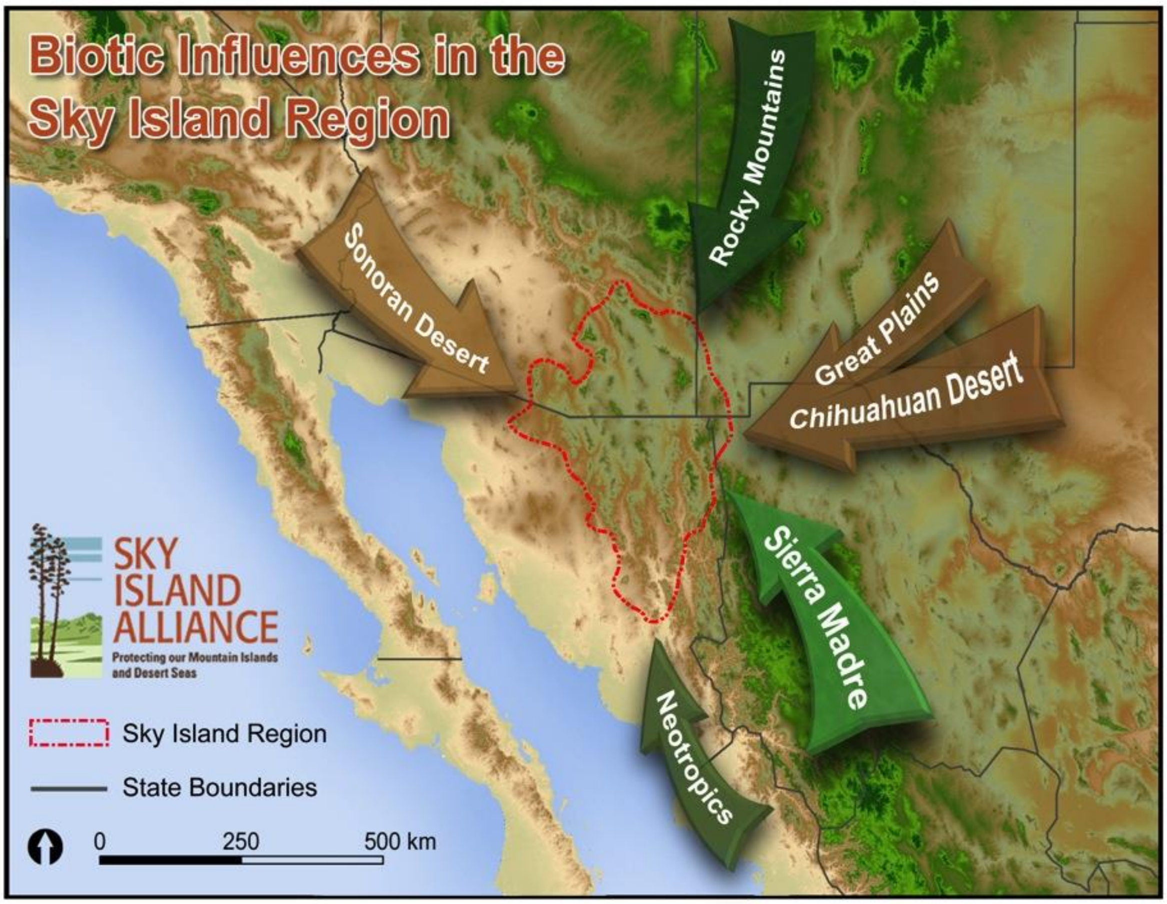
We used the Springs Ecosystem Assessment Protocols to collect information on ecological integrity and threats to natural resource values at individual spring sites. This protocol specifically includes fire influence. Flow regulation and adjacent land conditions exert the most influence on springs in the Upper Santa Cruz River study area, followed closely by road, trail, and railroad impacts. At springs in areas that had recently burned (in the last 15 years), erosion - including loss of soil function and changes in microhabitats and runout channel geometry - seemed to be the most pronounced impacts of fire. Many of these springs were in areas that previously had canopy cover and forested cover upslope of the spring emergence and have experienced a decrease in flow. To identify springs with potential for restoration actions or protective management actions and offer some prioritization of these, we plotted springs based on their natural resource condition and risk scores. Priority spring sites for restoration and protection are described in detail in the results section. Specific management recommendations for individual springs are included in the springs' reports in Appendix B and C, and more general regional recommendations for management are included in the discussion section.

Introduction

Project Need – Adapting to a Changing Climate

This project developed baseline information on springs ecosystems in the Sky Island Region of southeastern Arizona, southwestern New Mexico, and northern Sonora and Chihuahua. The Sky Island Region is located at the heart of the Desert Landscape Conservation Cooperative (Desert LCC) region. It is characterized by forested mountain ranges, “sky islands,” surrounded by intervening desert and grassland “seas” and is influenced by the Sierra Madre, Rocky Mountains, and Sonoran and Chihuahuan Deserts (Figure 1). Its diverse habitats and topography support many species at the edge of their range, and rare and endemic species, making it an incredibly biologically diverse region.

Figure 1: Map of the Sky Island Region



Arizona is the second most arid state in the continental United States yet likely contains the highest concentration of springs (Springs Stewardship Institute, 2013). Springs in the Sky Island Region have recently begun to be systematically inventoried in part through a previous Desert LCC supported project to inventory springs in the Cienega Creek Basin (Misztal et. al, 2013). Information that does exist on springs continues to be predominately in inaccessible formats, years or even decades old, or only available by jurisdiction. Lack of information on the location, status, ecology, discharge sphere, and other information hinders the understanding and effective stewardship of springs ecosystems (Stevens and Mertesky 2008, Misztal 2011).

The first step toward achieving enhanced management of springs is identifying the current status of springs, including actual location on the ground; current management; human or natural alterations; flora and fauna supported; water production; status of underlying groundwater basin; and contribution of these waters to the watershed where they are located.

The need and framework for this project was identified at a series of three regional climate change adaptation workshops convened by Sky Island Alliance in 2010, 2012, and 2013.[1] Workshops were designed to identify key natural resource and management vulnerabilities to climate change, and to collaboratively develop implementable strategies to reduce vulnerabilities. Workshop participants included federal, state, and local resources managers, scientists, conservationists, and private land-owners (more information is available at www.skyislandalliance.org/adaptationworkshops.htm and www.Ecoadapt.org/workshops.htm).

Natural resource managers in the Sky Island Region collaboratively developed climate change adaptation strategies to respond to the most pressing threat in the region for natural systems: increasing aridity and scarcity of available water (Misztal 2011; Misztal et al. 2012, Misztal 2013, Hansen 2013). Springs emerged as a focal natural resource in this discussion. Strategies developed to reduce the vulnerability of springs and wildlife included (see also Figure 2):

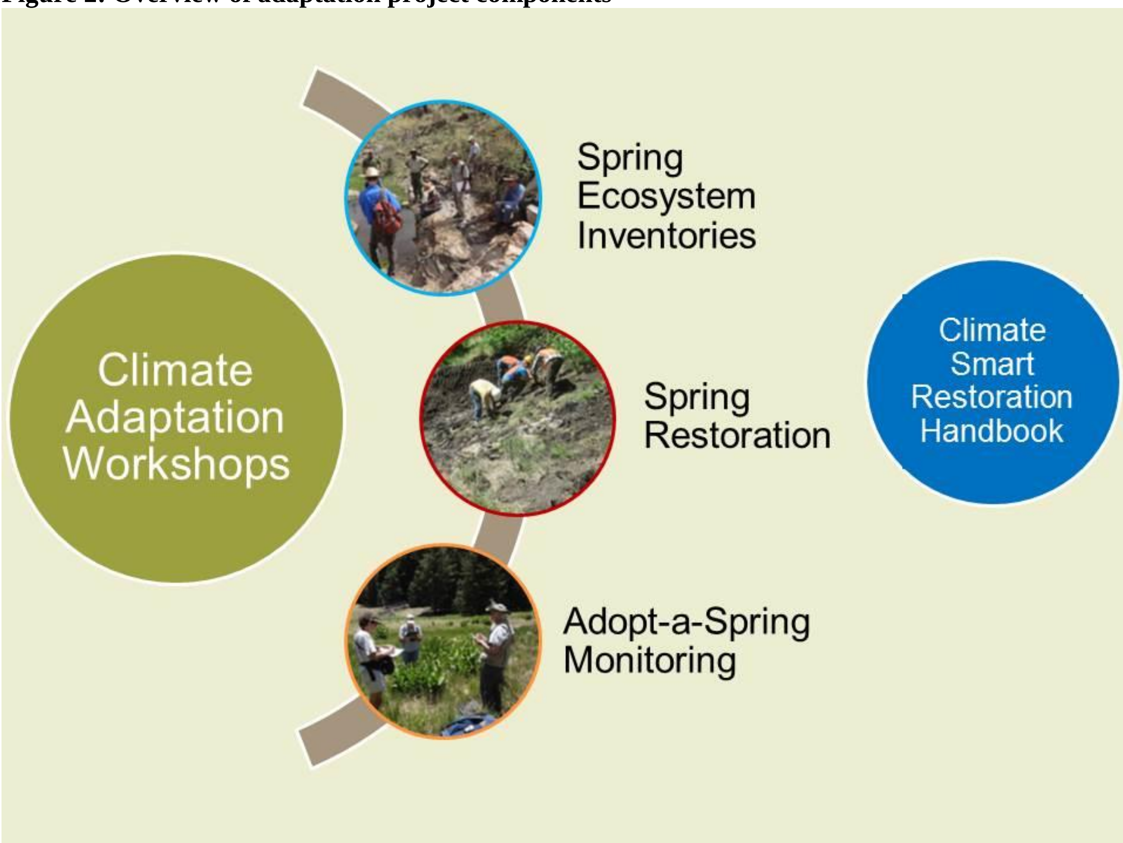
- Inventory spring locations, conditions and characteristics, species presence and management status.
- Coordinate data sharing across jurisdictions to understand springs in a regional context.
- Prioritize springs for restoration and protective management.
- Coordinate management across jurisdictions to implement protection and restoration of spring ecosystems.
- Create climate-smart spring restoration methodologies.
- Conduct upland habitat restoration to increase recharge and decrease erosion – include fire considerations.
- Conduct post-fire monitoring of springs and upland habitat to understand effects

At the most recent workshop in May of 2013, participants indicated they are highly concerned about how fire and pre-fire treatments may be affecting springs ecosystems. They also indicated interest in working with trained Sky Island Alliance volunteers to implement climate-sensitive monitoring at high priority springs. There is a regional trend

[1] These workshops were supported by The Kresge Foundation and the Nina Mason Pulliam Charitable Trust.

of increased size of high-severity wildland fires and earlier onset of fire season, both of which will likely lead to negative impacts on springs, particularly rheocrene-type springs that are located in channels and are often the source of perennial water and riparian habitat. Changes in fire behavior could also lead to springs becoming increasingly important as a source of perennial water in an otherwise arid landscape and as species refugia following fire events in Sky Islands.

Figure 2: Overview of adaptation project components



Springs in the Sky Island Region exist in a variety of states ranging from undeveloped and relatively intact to mostly transformed by installation of structures such as spring boxes or earthen stock tanks. In many instances across public and private lands, springs were altered for human use but are no longer being used for the purpose for which they were originally altered, or have been modified far beyond what is necessary for their current use. Many opportunities exist to fully or partially restore springs to a more natural state that will enhance their value as habitat, water for wildlife, and climate refugia. Due to the combination of decreasing management resources and increasing threats to resource integrity, there is a need to prioritize where and how to focus management and restoration activities to generate the best outcomes possible for water and wildlife.

Project Background and Goals

SIA is a non-governmental organization that works to protect and restore the rich natural heritage of native species and habitats in the Sky Island Region. We work with volunteers, scientists, land-owners, public officials, and government agencies to develop science to inform regional conservation, determine conservation priorities, restore healthy landscapes, establish protected areas, and promote public appreciation of the region's unique biological diversity. Because of our long-standing collaborative relationships with land and resource managers and our large corps of skilled volunteers, we were in a unique position to spearhead this project.

SIA initiated this project to enhance the conservation and restoration of keystone spring ecosystems in the Sky Island Region. To do this, we developed baseline information on springs to inform interested agencies and citizens on the condition of these resources and on management actions that can be taken to enhance their resilience in the face of climate change; we also developed tools, guidance, and capacity to support climate-savvy management, restoration and monitoring of springs at the landscape level.

This project began in September of 2013 and was completed in September of 2015. The specific goals of the project were to:

- Reduce the vulnerability of springs to climate change and non-climate stressors.
- Increase regional understanding of springs ecology, management status, springs' contribution to landscape-level resilience, fire impacts on them, and their relationship to the hydrologic areas in which they are located.
- Build and enhance technical capacity to collect and understand critical baseline information on unstudied springs and to monitor them long-term.
- Help managers adapt management of springs to climate change and promote climate change adaptation practices at the landscape scale.
- Guide future spring restoration efforts to increase the resilience of ecosystems in the face of climate change impacts and non-climate stressors.

We worked collaboratively with land and resource managers to identify priority areas in which to conduct spring inventories and assessments and collected new data on priority springs in the region. We worked with the Spring Stewardship Institute to develop a climate-smart Spring Restoration Handbook for the state of Arizona, and we developed and implemented a pilot effort (Adopt-a-Spring) to monitor springs long-term to understand climate change and restoration effects on them.

Springs Ecology

Springs occur where groundwater reaches the earth's surface (Meinzer 1923). Springs are scattered over all landscapes in the arid southwest, and in the arid regions of North America, they often capture our imagination as lush oases within harsh landscapes. There are many lenses through which to view the value of springs: archaeologists have shown how springs were the focus of many Native American activities; hydrologists understand them as windows into ground water systems; ecologists see them as biodiversity hotspots; ranchers often rely on them as water sources for livestock; and conservationists recognize that they are important riparian and aquatic systems critical to the survival of many obligatory spring-dwelling animals and plants. In spite of this recognition, springs have been largely neglected as important cultural, scientific, and economic resources, and most have been altered by human activities. As a consequence, few springs have retained their natural character, and their fauna have experienced some of the highest extinction rates known in North America (Stevens and Meretsky 2008). Stevens and Meretsky characterize springs as among the most threatened ecosystems.

Springs often function as keystone ecosystems – although they occupy a small area on the landscape, they play a disproportionately large role in the ecology of the surrounding landscape (Peral and Stevens 2008). Despite their utility in land management and the growing recognition of their ecological importance, the functional and ecological status of springs remains largely unknown.

It has only been in recent years that a consistent classification system has been developed to describe springs ecosystems (Springer and Stevens 2008). This system provides a framework for springs ecosystem conservation, management, and restoration. Springer and Stevens (2008) identify 12 types of springs which they refer to as "spheres of discharge." The following eight spring types are relevant to this project. Please see Springer and Stevens (2008), and Appendix A for further information.

- *Rheocrene* springs are flowing springs that emerge in one or more channels.
- *Helocrene* springs emerge from low gradient wetland and often have indistinct or multiple sources seeping.
- *Hillslope* springs emerge on a steep (30-60°) slope and often have indistinct or multiple sources.
- *Limnocrene* springs emerge in pools.
- *Mound-form* springs emerge from (usually carbonate) precipitate mounds or peat mounds.
- *Hanging Garden* springs usually emerge horizontally along a geologic contact along a cliff wall and display dripping flow.
- *Cave* springs emerge in a cave in mature to extreme karst with sufficiently large conduits.
- *Hypocrene* springs are buried springs where flow does not reach the surface, typically due to very low discharge and high evaporation or transpiration

Other Regional Efforts Benefiting from this work

In the Sky Island Region, numerous partners were already mapping, monitoring, inventorying, or otherwise paying some attention to select springs under their stewardship. We coordinated with the following extant initiatives during our project: a spring snail assessment on Fort Huachuca, efforts to document springsnails in Arizona led by the USFWS and AZGFD, identification of springs in the Santa Rita Mountains near a proposed copper mine, surveys of water resources in the Tumacacori Mountains to monitor bullfrog occurrence and native frog populations, surveys of lowland leopard frog populations and known locations in the Tucson Basin (on county, private, USFS and NPS lands), a spring inventory effort and ongoing *tinaja* and spring monitoring in association with ranid monitoring at Saguaro National Park, efforts to catalogue *Carex* and *Juncus* species in Arizona and develop a guidebook, restoration efforts at various springs on federally and privately managed land, an effort to inventory all springs on Pima County Conservation lands and wet dry surveys of their known springs, recovery efforts for the endangered

Chiricahua leopard frog including restoration of aquatic habitat and documentation of potential habitat, and documentation of water rights on the Coronado National Forest.

At the start of the project, the Coronado National Forest had developed survey protocols for documenting beneficial uses of water at springs and other water-dependent ecosystems. Pima County acquired land and resource management responsibilities on 225,000 acres of land in eastern Pima County over the past 6 years and was collecting information on the location, status, and trends of key natural resources and threats to those resources. Pima County has a long history of data collection on riparian and aquatic features through regional assessments to inform and implement the Sonoran Desert Conservation Plan (see www.pima.gov/cmo/sdcp/). For the duration of this project, Sky Island Alliance worked under complimentary funding to conduct restoration work at 9 springs sites to improve ecological resilience to climate change, as well as working within a recently burned drainage in the Chiricahua Mountains to install low-tech erosion control structures and native plants that will provide cover and food for wildlife and restore the seedbank.

Methods

This project involved a combination of field data collection, spatial and other analysis of spring inventory and assessment information, coordination with a diversity of partners stewarding springs, and partner engagement in formal management including climate change adaptation planning. This section describes our methods and approaches.

Study Area Selection and Description

This project grew directly out of collaborative climate change adaptation planning efforts that involved scientists, resource managers, land owners, and conservationists. The project was designed to be responsive to the information and management needs of regional land managers. We engage a broad array of agencies, conservation organizations, tribes, research institutions, and private landowners that had attended regional climate change adaptation workshops, had previously expressed interest in springs or that we knew had springs resources under their stewardship. Throughout the project we have asked participants to share their management interests in springs, existing regional data, and to identify who they thought should be involved.

We decided to focus our efforts on one hydrogeologic/watershed area in the region in which to inventory and assess a random sample of springs. In January 2014, we held an outreach and coordination meeting with project partners where we shared findings from our previous 2-year springs inventory and management planning project in the Cienega Creek hydrogeologic area; reviewed components of this current project; discussed partners' work in the region related to springs; and reviewed maps and information and gathered partners' input on selection of the next the study area for this project. There were 21 attendees from the following agencies and groups:

Federal Agencies - U.S. Geologic Survey**,** Bureau of Land Management (Safford Office)**,** US Fish and Wildlife Service**,** US Forest Service (Coronado National Forest)**,** National

Park Service (Saguaro National Park and the Sonoran Desert Network), and the Desert Landscape Conservation Cooperative

State agencies- Arizona Game and Fish Department

Local agencies- Pima County, and Pima Association of Governments

University of Arizona - Arizona Water Resources Research Center

Non-governmental Organizations - The Nature Conservancy, Arizona Native Plant Society, Bat Conservation International, Springs Stewardship Institute

We selected the Upper Santa Cruz River Basin for our study area, which encompasses 274 mapped springs and includes land managed by the USFS, NPS, BLM, Pima County, TNC and a variety of private landowners (Figure 3 and Figure 4). The area includes a diversity of habitat types, six distinct mountain ranges, and a variety of areas with high conservation value. We utilized GIS and worked with the Springs Stewardship Institute to ensure springs data for the study area was up to date and we identified a clustered random sample to allow us to inventory springs representative of the diversity of elevations, habitats, mountain ranges and land ownership in the study area.

The Upper Santa Cruz River study area is comprised of 2,440 square miles (6,320 square km) and includes 274 documented springs. The study area encompasses portions of Pima, Santa Cruz, and Pinal in southern Arizona and abuts the U.S.-Mexico border. The study area contains the following biotic communities (Brown and Lowe 1981) Semidesert Grassland (855,016 acres), Arizona Upland Sonoran Desertcrub (459,930 acres), Madrean Evergreen Woodland (206,647 acres), Interior Chaparral (24,419 acres), Petran Montane Conifer Forest (14,205 acres), and a small area of lower Colorado River Sonoran Desertscrub (1,298 acres) (Figure 5).

Significant management units in the Upper Santa Cruz Basin study area include the Santa Rita, Rincon, Tumacacori, Huachuca, and Santa Catalina Ecosystem Management Areas of the Coronado National Forest managed by the U.S. Forest Service (USFS); Saguaro National Park managed by the National Park Service; and other conservation lands managed by Pima County.

Information Sources

Prior to conducting field work, we attempted to locate all springs in the Upper Santa Cruz River Basin study area. We utilized a spatial data set from the Springs Stewardship Institute that included data from the Arizona Land Resource Information System (1993), Arizona Geologic Information Council (2008), the Coronado National Forest, Pima County, The Nature Conservancy, SWCA Environmental Consultants, and the USGS and the National Hydrology Dataset. Through a complimentary project funded by the Desert LCC, the Spring Stewardship Institute brought all of these data sources together into one seamless dataset and removed duplicates. We used Google Earth, Google Maps, hikearizona.com, and topographic maps to assist in locating and navigating to springs.

Random Sample Design

In order to develop an understanding of springs' health, characteristics, and management needs at a landscape-level, we used a clustered random sample design to determine sites for survey. Survey sites were selected by analyzing all 274 springs in the study area based on their X, Y, and Z coordinates to create "spring clusters," then randomly selecting one or more springs within each cluster to reach a random sample size of 50 springs. We choose a sample size of 50 to get adequate representation of springs across the study area based on expert input from Dr. Larry Stevens of the Springs Stewardship Institute. We used a cluster-based random sample to ensure springs were inventoried across a range of elevations, levels of geographic isolation, and ownership status in order to support a landscape scale ecosystem assessment. This methodology ensured we were not limiting our survey sites to springs that were well-known, easily accessed, or of high management interest to our partners, and insured we were gathering a broad sample of springs.

If we were unable to visit a spring in the random sample of 50 due to access or other issues, we moved down the list to the next spring in the sample. In addition to the randomly selected springs, we opportunistically assessed "non-random" springs that were in close proximity to random springs, and select springs that were of high management concern or high priority to partners. Figure 4 shows the randomly selected and other springs that were visited over the course of this project.

This study framework provided two crucial types of information—a landscape-scale assessment of spring ecosystems within the Upper Santa Cruz River study area and specific data on the ecological conditions at individual springs.

Figure 3: Map of study area location in the Sky Island Region.

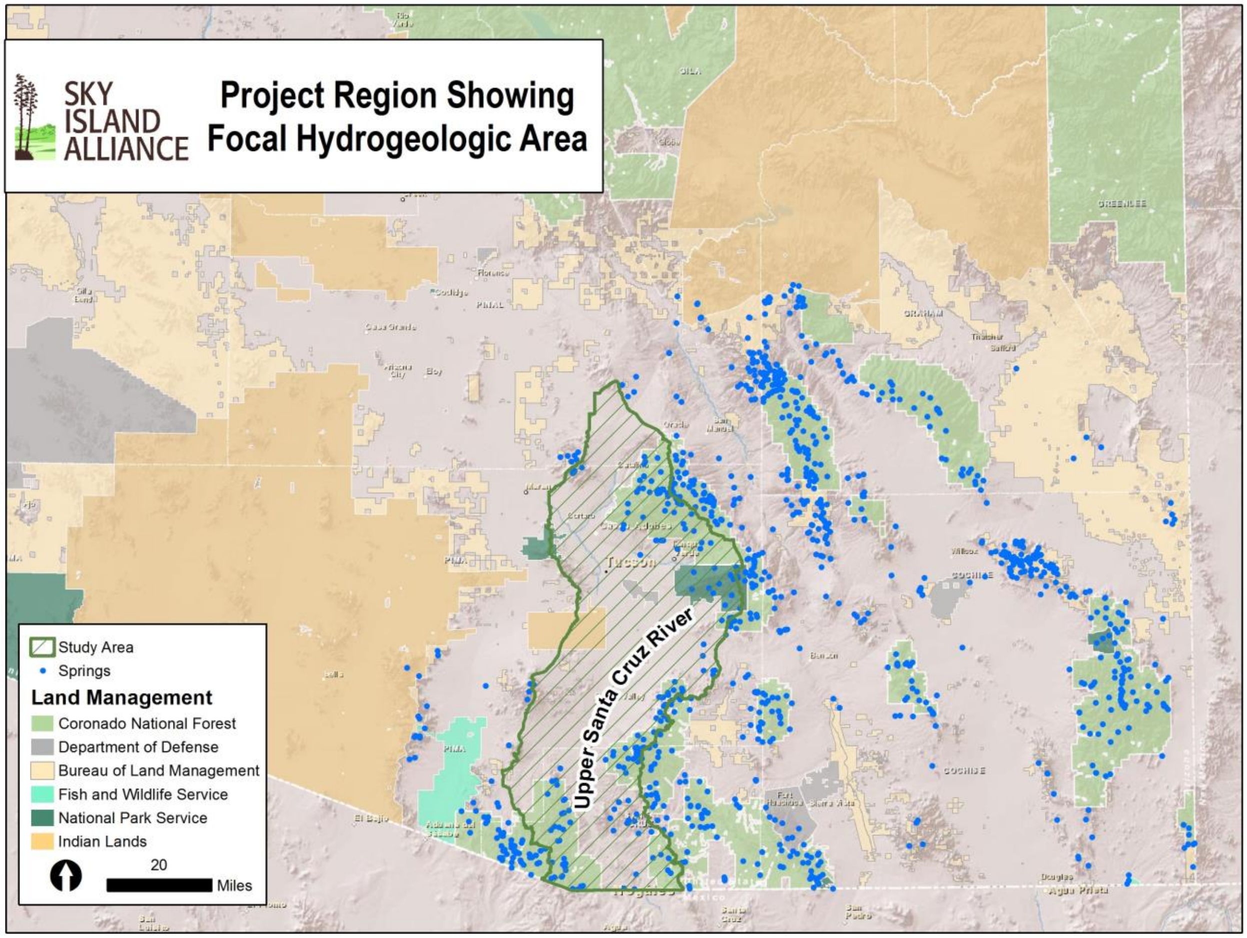


Figure 4: Map of springs surveyed in study area.

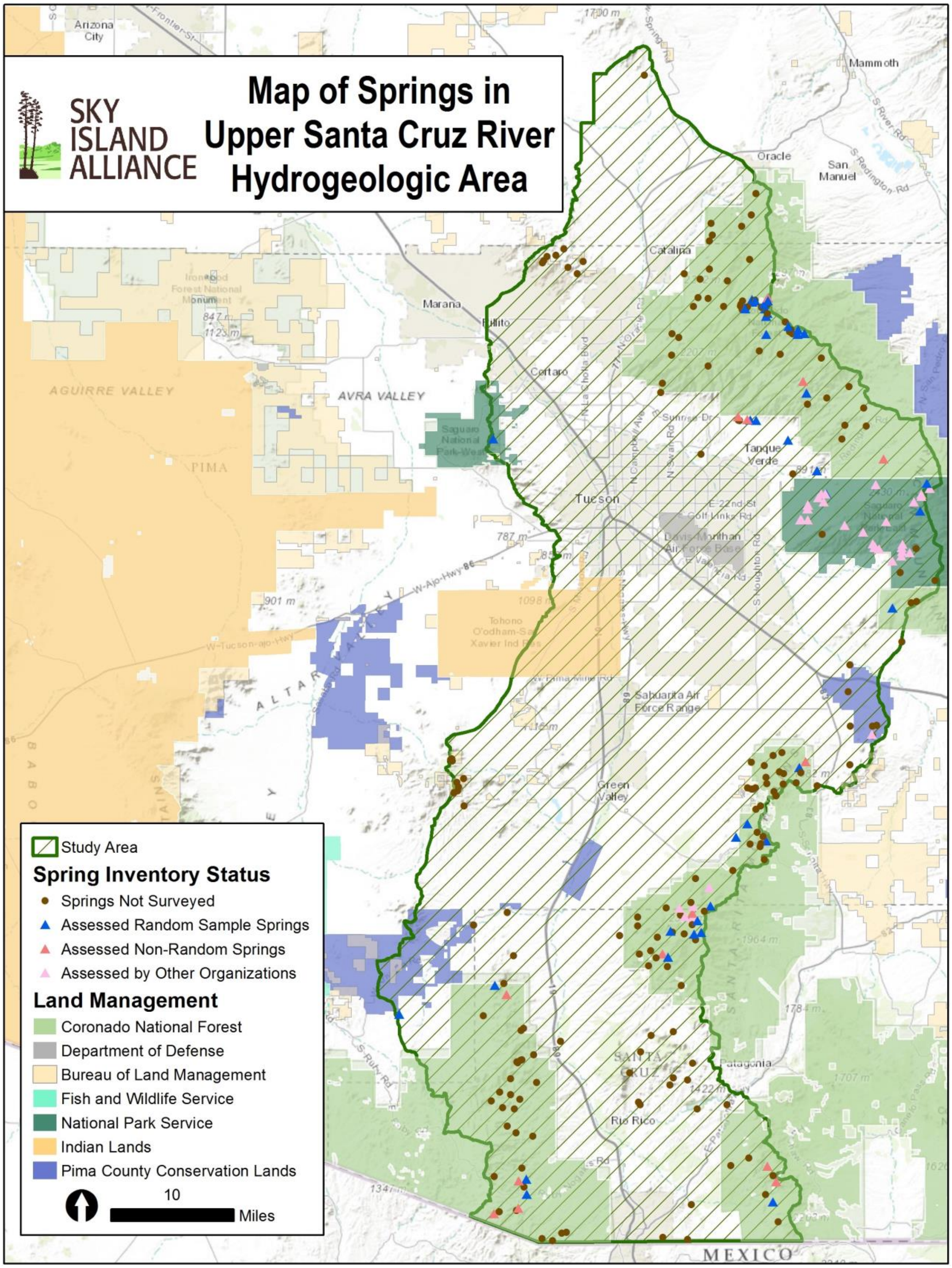
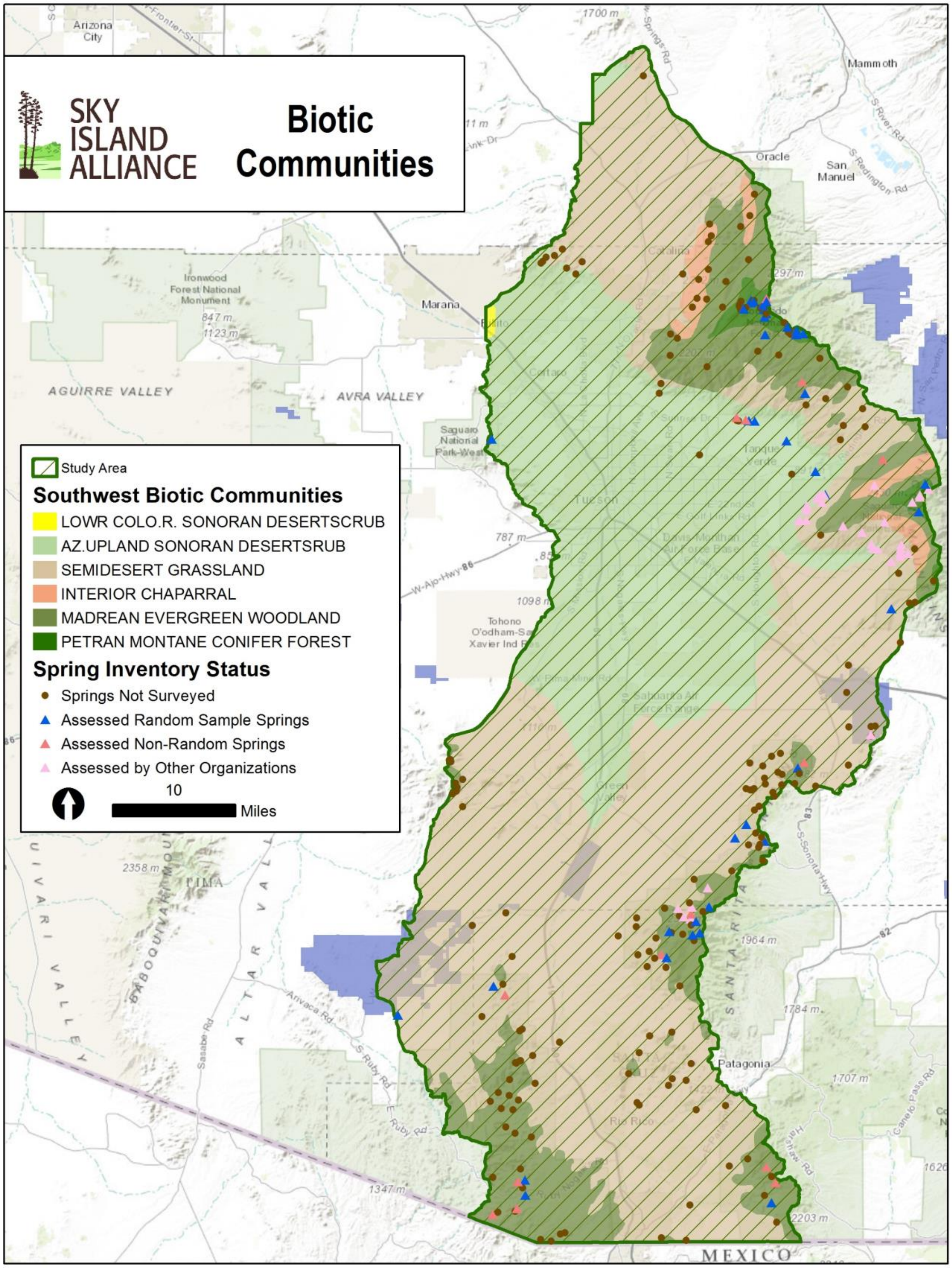


Figure 5: Map of biotic communities in the study area

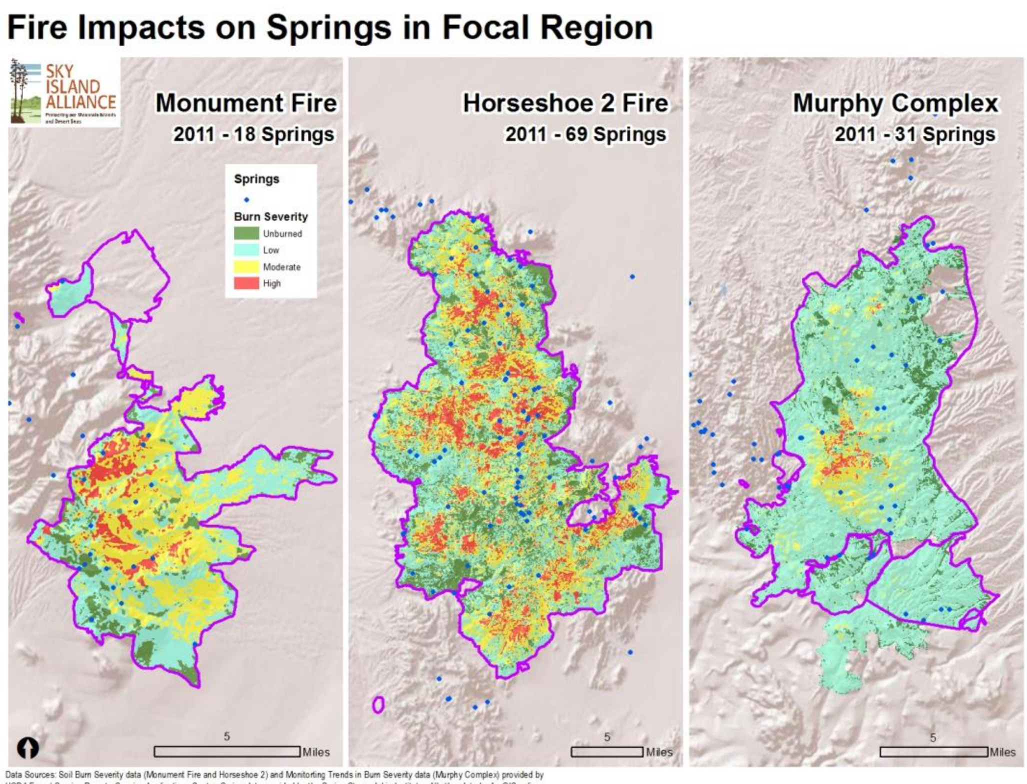


Selection of Fire Influenced Springs for Study

Project partners and collaborators indicated to us that there is no existing data describing the condition of springs in relation to fires or documenting how fuel treatments may impact them. To address this information gap, we selected springs to inventory and assess specifically for fire effects that were in addition to random sample springs in the Santa Catalina and Santa Rita mountains in areas of recent fire. We based our selection on a combination of input from the Coronado National Forest and a spatial analysis of spring locations in relation to burn severity. We mapped springs against Burned Area Emergency Response (BAER) Soil Burn Severity data and talked with managers working on FireScape and on-the-ground fire response on the Coronado National Forest.

At the start of the project there were a number of recent large fires in the Sky Islands in areas of interest to the Forest and Sky Island Alliance (Figure 6).

Figure 6: Overview of springs potentially impacted by fire.



We choose to focus our fire survey efforts in the Pinaleño, and Chiricahua Mountains. There were planned fuel treatments for 2,641 acres of high elevation spruce-fir and mixed-conifer forests within the Pinaleño Ecosystem Restoration Project area (PERP). PERP's principle concern is protecting habitat for the endangered Mount Graham red squirrel and reducing the risk of stand-replacing fires. Eighty-five springs have been mapped within the approximately 200,000 acre Pinaleño Ecosystem Management Area (EMA). One of these springs is within the PERP area, and an additional 9 are immediately adjacent to it.

Assessments can provide baseline data on the conditions of springs in advance of fuels treatments and create a monitoring framework for detecting the influences of fuels treatments on springs. PERP offers one ideal study environment with numerous planned treatments including prescribed fire, lop and scatter, pile and burning, and small-diameter thinning. Understanding the interplay of these management techniques with springs' ecosystems will be valuable for future landscape-scale restoration projects.

Field and Analysis Methods

Spring Inventories and Assessments

To collect baseline data on springs in the Upper Santa Cruz River study area, we used inventory and assessment protocols developed by the Springs Stewardship Institute (Stevens et al. 2012) and adapted for use with trained volunteers. Trained volunteers were the main workforce for accomplish springs surveys (Figure 7). Volunteers that participated in the project had varying levels of naturalist or scientific expertise. To accommodate this, we developed protocols that struck a balance between a Type I Inventory, that collects solely geographic information on springs, and a Type II Inventory that collects physical, biological, geomorphological, geological, human impacts, and administrative context variables for springs (Ledbetter et al. 2010; Stevens et al. 2012).

Survey teams, typically ranging in size from 2-5 people, visited springs. To ensure data quality, consistency, and compliance with survey protocols, volunteer teams were always accompanied by an SIA staff member trained in the protocols, or by a reliable substitute from a partner organization. We structured volunteer teams so that a diversity of expertise was represented. For example, a staff-volunteer team might include a birder, a botanist, a geographer, and a biologist. We conducted field work through a combination of day trips to isolated springs and volunteer weekends where we camped at a single location that was in close proximity to a cluster of springs.

Figure 7: Volunteers conduct a spring inventory at Barfoot Park in the Chiricahua Mountains

To maximize field data collected within the funding period and volunteer engagement opportunities, we conducted surveys throughout the year. Ideally, biological inventory would be conducted during the growing season to capture flowering and breeding, while hydrological and geological surveys would be conducted in winter to capture peak baseflow information (Stevens et al. 2011). These opposing considerations for timing of surveys highlight the importance of making additional site visits in different seasons, and of monitoring. The data collected through this project provide a snapshot in time of each of the springs visited.

At all springs sites that were located in the field, the following inventory data was collected:

Site Overview Information: includes GPS location, elevation, spring sphere of discharge, site condition at time of visit, site description, directions to site, surveyors' names and survey time. The spring sphere of discharge is based on the combination of source flow and physical characteristics of the site (Springer et al. 2008) (see Appendix A for more information). This overview information is necessary to map the spring, re-locate the spring during subsequent visits, track changes in spring condition over time, and to relate springs to management areas and activities. Equipment used included a GPS device, a compass, and a clinometer.

Site Map: includes a map with a scale, area measurements, true north, the location of photographs, the location of variables measure including water, GPS and solar radiation measurement points, and spring microhabitats labeled (Figure 8). Maps were drawn to include the area directly influenced by the spring. The sketch map synthesizes locations of geomorphological landmarks and biological characteristics, allows for repeat measurements, and measures the area of springs sites and microhabitats. Equipment used included a 30 or 50 meter tape measure and graph paper.

Photo Documentation: includes an overview photo of the site taken near the source point looking down channel, a secondary photo likely taken below spring emergence looking up channel, and any other objects of interest. Photos provide an overview of site geomorphology, hydrology, biology and condition.

Solar Radiation: includes recording a sunrise and sunset time for each month of the year. A Solar Pathfinder was used to record a total solar budget for the site. The amount of solar budget at a site determines light energy available for photosynthesis, duration of freezing in winter, evaporation and relative humidity and is therefore an important factor in microclimate (Stevens et al. 2006; Stevens et al. 2011). A Solar Pathfinder is a relatively inexpensive tool for collection of solar radiation data and provides finer resolution than can be provided through a GIS analysis. This is important when surveying springs that are very small in total area, or are located on vertical surfaces or in steep terrain.

Flora and Fauna: includes lists of plant and animal species present or identifiable by sign or calls with careful attention to the presence of sensitive and invasive organisms. This was done to the best of the ability of the survey team and was intended to get an initial snapshot of the species present at springs.

Flow: Flow rate measurements were taken when possible. Surveyors used a simple timed volume capture protocol. Flow is one of the most important and useful variables for understanding what biotic components a spring can support and the level of its functioning, and is sensitive to anthropogenic influences such as water extraction. Equipment used included PVC piping of various sizes, calibrated capture cups ranging from .75 L to 1.5 L, and a stopwatch.

Water Quality: includes pH, specific conductance, temperature and dissolved oxygen. Water quality was measured as close to the source as possible. Water quality measurements were taken in the field using the Hannah Handheld Combo meter that was calibrated at the start of every field work day. This instrument was used to measure pH, specific conductance, and temperature.

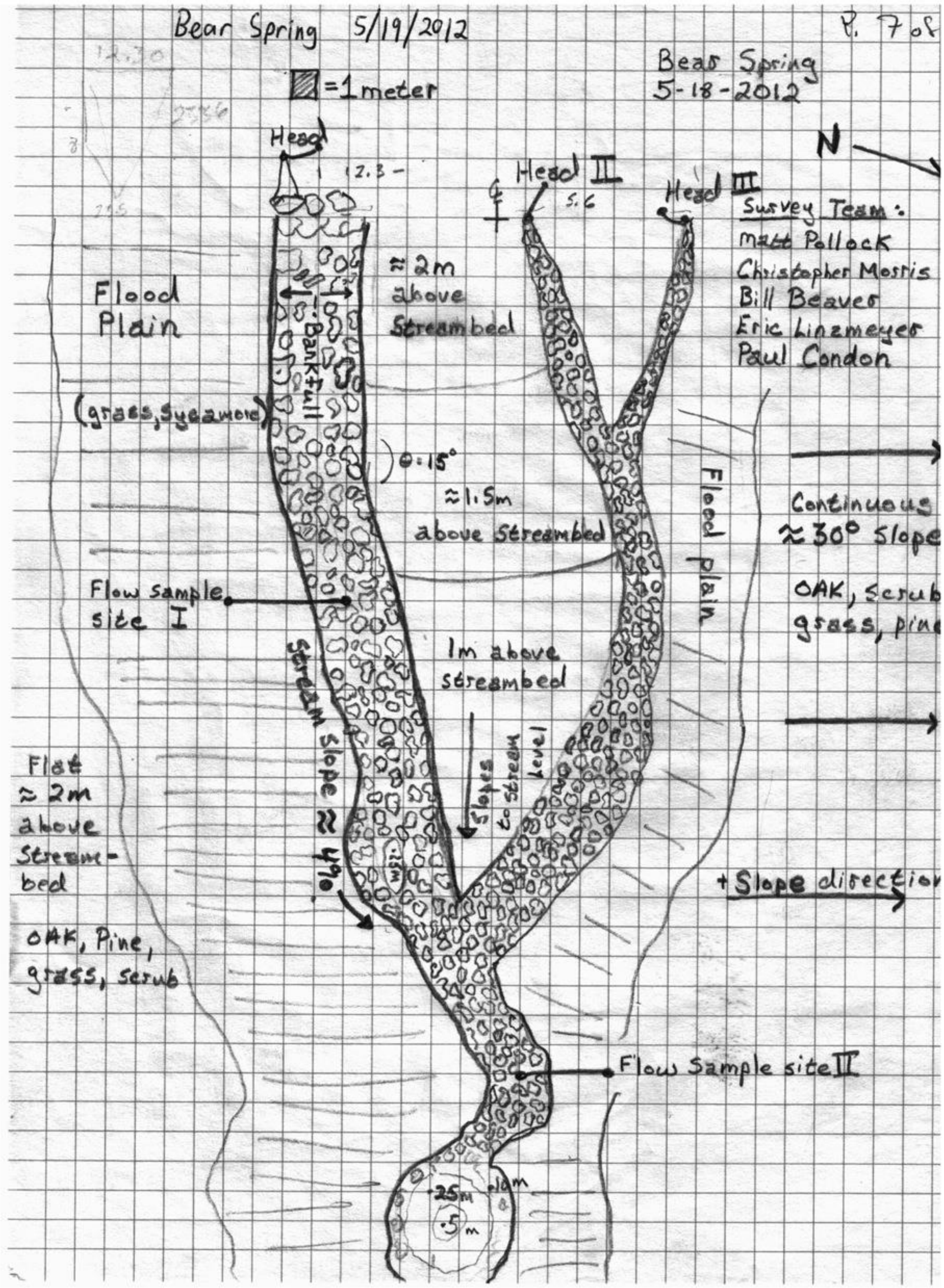
In addition to the inventory data listed above, crews performed Springs Ecosystem Assessment Protocols (SEAP). This set of protocols was developed by the Springs Stewardship Institute and collects information regarding the ecological condition, risks, and restoration potential of springs. Characteristics scored by the assessment fall under the following categories: Aquifer/Water Quality, Geomorphology, Habitat, Biotic Integrity, Human Influence, and Administrative Context. Specific characteristics under each of these categories are scored on a scale of 1-6 and are given a score for both condition and risk based on a detailed scoring rubric. See Appendix A for detailed assessment protocols, scoring rubric, and field forms. Assessed springs can then be ranked based on specific stewardship objectives, providing a roadmap for management options at a specific spring. This information can also be examined in aggregate across a study area or region of interest to develop an understanding of overall conditions and threats for the region. Springs inventories and assessments provide information on the springs condition and ecologic contribution in context with local and regional threats including ground and surface water extraction, contamination, livestock use, human alteration of the site, recreational impacts, and climate change.

New for this project

Based on input from management partners, we added several new protocols to our spring inventories this year: springsnail surveys, water rights documentation, and water sample collection. We coordinated with the Arizona Game and Fish Department and the U.S. Fish and Wildlife Service to incorporate their springsnail protocols into our surveys and 3 SIA staff members attended a springsnail survey training at the outset of the project. We worked with the Coronado National Forest to incorporate a new survey protocol that captures information on spring characteristics in a format suitable for the Forest to use as documentation of beneficial uses of water for water right adjudication purposes.

During this project we began coordinating with researchers at the University of Arizona and USGS who have an interest in analyzing isotopic composition of water samples from springs to determine flow path and recharge type. We began collecting water samples to share with them. This complimentary analysis will provide much needed information to inform springs management, protection and restoration, and will improve our understanding of springs ecosystems and groundwater hydrology in the study area.

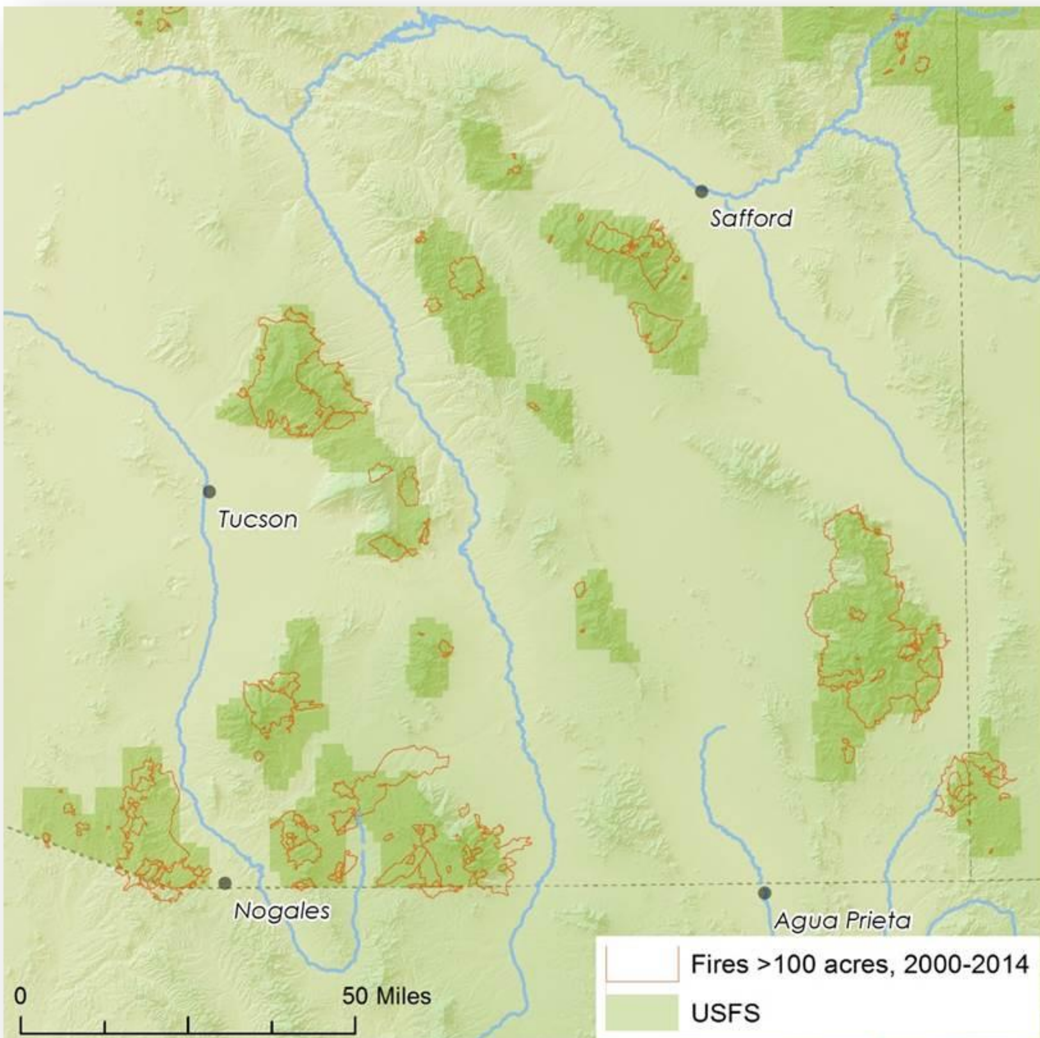
Figure 8: Sample Site Map



Cataloguing Effects of Fire at Springs

The Coronado National Forest is the major land manager of forested Sky Island habitat in the Sky Island Region (1.7 million acres). Since 2000, 46% of the Forest has experienced wildfire from 130 separate fires, 128 of which were larger than 100 acres. Thirty-four percent of springs on the Coronado National Forest are within a burn perimeter (Figure 9). We conducted inventories and assessments at 24 springs in the Pinaleño and Chiricahua Mountains on Coronado National Forest land within burned areas or the PERP.

Figure 9: Overview of fire perimeters on the Coronado National Forest.



We used the same inventory methods (Stevens et al. 2012) adapted for use with volunteers to inventory and assess springs in areas that had recently burned or were in areas of high danger for potential fire (Figure 10). To better capture fire effects, we added a new Springs Ecosystem Assessment Protocol category addressing negative effects of fire at springs, as well as paying special attention to documenting site condition and observations in the notes.

Figure 10: Volunteers inventory and assess Lower Rustler Park Spring in the Chiricahua Mountains.

To analyze how these springs were affected by fire, we calculated the average burn severity within a 50 m and a 250 m radius around each spring (on a scale of 0-4). We used the Madrean Archipelago REA burn severity distribution layer, which depicts the maximum burn severity of fires from 1997 through 2011. We categorized an average 0-1.24 as very low burn severity, 1.25-2.24 as low burn severity, 2.25-3.24 as moderate burn severity, and 3.25-4 as high burn severity. To understand if springs were less vulnerable to fire than their surroundings, we calculated the difference between the 50 m radius average and the 250 m radius average (Burn Severity Difference). We also calculated average aspect within each 50 m radius from a 30m DEM.

Adopt-a-Spring Monitoring

Partners at the January 2014 outreach and study site selection meeting were very interested in the new Adopt-a-Spring component of this project, and many expressed interest in participating in site selection and methodology development. Some partners had particular sites in mind, while others had done similar work and had protocol suggestions, particularly National Park Service affiliates. To accommodate interest and capitalize on sharing of expertise, we held a partner meeting in April 2014 focused on site selection and protocol development. We selected 5 sites to monitor with volunteers and identified two additional sites that managers are regularly visiting where we can collaborate with them to collect similar monitoring information. In addition to managers' needs, we took into consideration recent restoration efforts at these sites, potential future restoration efforts, the need for reference sites in the region, and the realities of asking volunteers to monitor these sites, i.e. accessibility and appeal. We recruited volunteers and formed spring teams at a volunteer orientation meeting and kicked off monitoring in June 2014. In April 2015, we added a sixth site monitored by the Cienega Club, the University of Arizona's watershed restoration student club.

The 6 Adopt-a-Spring sites (Figure 11 and Table 1) include springs accessible by two-wheel drive or four-wheel drive, drives of 30 minutes to 3 hours, on and off-trail hikes, no hiking to hikes of 6 miles round-trip, a variety of land jurisdictions, a variety of spring types, and sites before and after active restoration, after passive restoration, and reference sites. This variety helped us better understand what types of site volunteers are willing to visit.

Figure 11: Adopt-a-Spring sites.

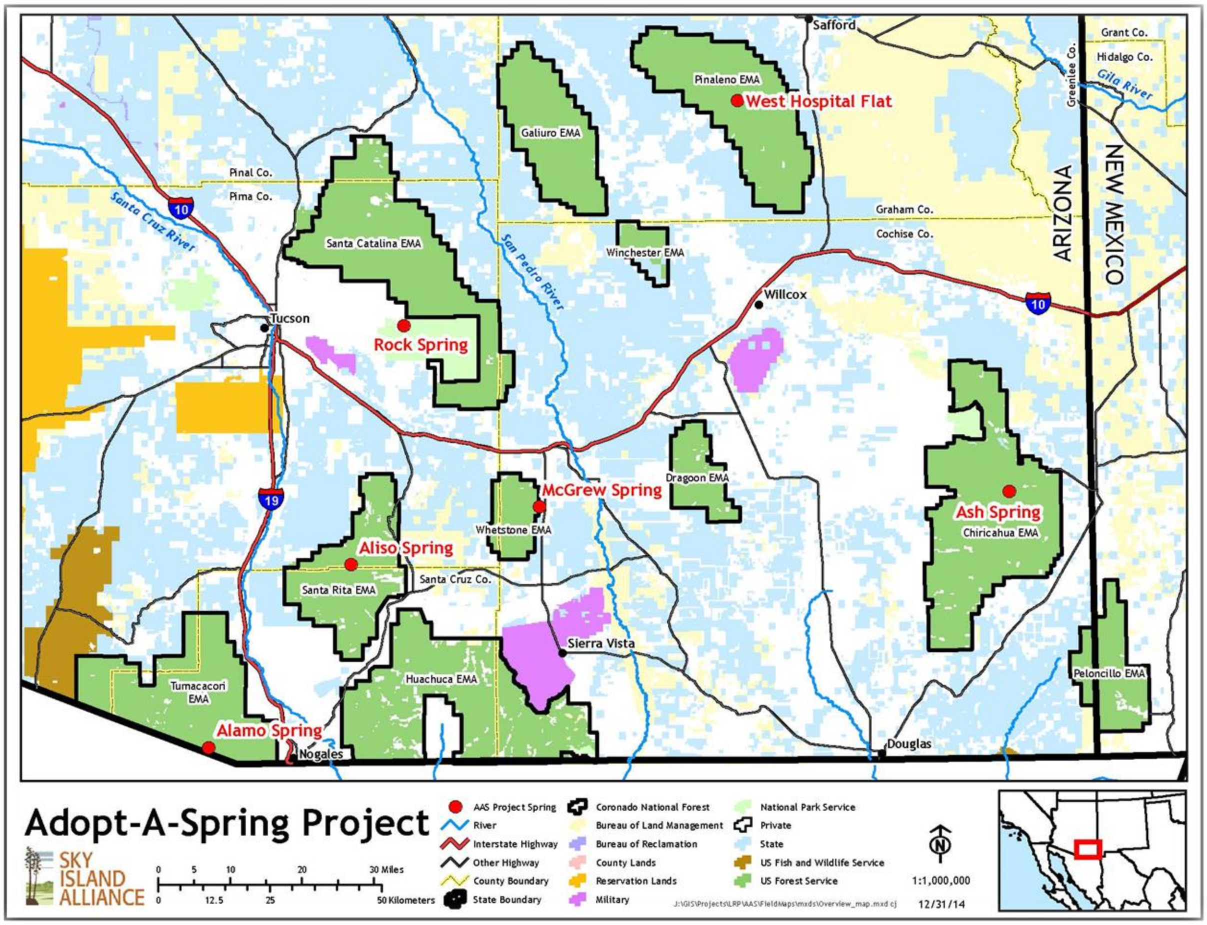
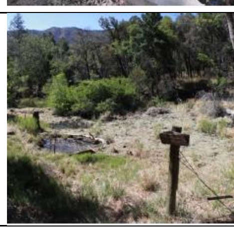


Table 1: Adopt-a-Spring site information.

Spring Name	Spring Photo	Conservation Targets	Spring Type	Land Ownership
McGrew		Pre-restoration, bats, mid-story pollinator plants	Hillslope	Kartchner Caverns State Park, Whetstone Mountains
Alamo		Chiricahua Leopard Frog	Rheocrene	USFS, Pajarito Mountains
West Hospital Flat		High plant diversity, high elevation wet meadow	Helocrene	USFS, Pinaleño Mountains
Aliso		Jaguar in the area, potential mine development nearby	Rheocrene	USFS, Santa Rita Mountains
Ash		Recently restored, wet meadow with ponds, Chiricahua leopard frog, bats	Hillslope, Helocrene	USFS, Chiricahua Mountains
Rock		Recently restored in-channel spring, lowland leopard frog	Rheocrene	NPS, Rincon Mountains

To capture seasonal data at spring sites we developed a schedule for monitoring that includes 5 survey windows to capture data during winter, spring, dry fore-summer, monsoon, and fall seasons (Table 2). Volunteer teams visited their site once during each monitoring window to record water quality, water flow data, and species occurrence. Because each site was unique, we developed ways to measure wetness at the sites by measuring features such as diameter of ponds and length of outflow. At Hospital Flat, a large helocrene site, we used LandSat data to measure the size of the wet meadow during each survey window; we performed a tasseled cap analysis to extract the wetness of pixels at the site, chose a threshold to differentiate the wet meadow from its surroundings, and measured the area of the wet meadow.

SIA staff conducted initial site visits with volunteers to orient them to their monitoring site and ensure proper compliance with the protocols. Collecting good botanical information has been a challenge for our volunteer based spring surveys. To address this issue with the Adopt-a-Spring sites (at which we particularly want good data to correlate with flow), we conducted a Botany Blitz in August 2014, at the height of the growing season. We recruited botanical experts from the region, including a *Carex* expert, and visited springs sites to develop plant lists by microhabitat.

Volunteer management primarily included sending out reminders prior to each survey window to volunteers to schedule their survey, setting up survey kits, and keeping volunteers supplied with survey kit materials, such as datasheets and calibration solutions for water quality. We occasionally assisted by setting up Doodle polls to assist volunteers in choosing a date. We recruited one volunteer for each site to serve as a team leader. This person stored the survey kit, returned completed datasheets and photos to us, and was responsible for scheduling surveys. Staff occasionally accompanied volunteers on surveys when there were too few volunteers available for a given window.

Table 2: Adopt-a-Spring monitoring windows.

Target Season	Months
Winter	January
Spring	March/April
Dry Summer	June
Monsoon	July/August
Fall	October/November

Developing Tools and Guidance in Support of Monitoring, Stewardship and Restoration

A key component of this project was to develop capacity to use springs assessment data, and to collaboratively develop guidelines and best management practices to inform stewardship of springs. We did this by training managers in use of the Springs Online database, hosting workshops on spring restoration, developing an Arizona Spring Restoration Handbook, and convening workshops focused on management and restoration of springs following fire.

Springs Online Database

In the fall of 2013, the Spring Stewardship Institute hosted a series of webinars and working sessions with Pima County staff to familiarize them with the database and its capabilities and to actually work with staff directly as they entered springs data to trouble shoot issues. In February 2014, we worked with the Spring Stewardship Institute to host a database webinar with staff from Saguaro National Park and the Sonoran Desert Monitoring Network. Webinars provided an overview of database structure and how best to integrate their data into the online database. This type of targeted training has proven effective in supporting organizations in transitioning their existing data to the database and in beginning to utilize the database in their workflow.

In February 2015, the Springs Stewardship Institute hosted another Springs Online Database Training available here (http://springstewardshipinstitute.org/online-database-training/). In 2015, we conducted a survey of registered database users to assess usability and troubleshoot potential problems. We received 25 responses indicating that generally users are returning to the site and pleased with the currently available tutorials.

Arizona Springs Restoration Handbook

We developed an Arizona Springs Restoration Handbook that walks practitioners through considerations and a process for planning and implementing springs restoration, including how to effectively consider climate change and fire effects. To develop the handbook, we worked with the Springs Stewardship Institute to hold two workshops with managers and practitioners. These workshops helped us scope the needs of managers engaged in spring restoration and to gather their expert input. Topics included: defining desired conditions and goals at spring restoration sites; restoration options by spring type; developing case studies for the most common spring types based on previous work; associated management strategies, including inventorying springs and prioritizing sites for restoration; legal and regulatory issues; and implementing, monitoring, and evaluating success.

This first workshop allowed us to identify key topics on which to focus. Based on participant input, we are working to develop and release the Handbook through a combination of media, including informational brochures, a published version for use in the field, and a website with more comprehensive information and links to additional resources. The second workshop included participants from a diversity of agencies and organizations; it focused on approaches for prioritizing which springs to restore (landscape scale) and what conservation targets to focus on at a particular site (local scale). We also focused on collecting practitioners' experiences and the techniques they used at different types of springs. After much discussion with workshop participants, we decided to include sustainable management and inventory and assessment techniques in the handbook to give context to restoration efforts. The Handbook contains the following sections:

- Arizona Springs Ecosystems
- Inventory and Assessment
- Springs-Dependent Species
- Restoration Planning
- Springs Restoration
- Springs Monitoring
- Field Forms and SEAP Criteria
- Hydrology Variables
- Worksheet and Equipment List
- Springs Restoration Plant Species
- Bibliography

The handbook brings together the current state of the knowledge about spring restoration in Arizona and provides a consistent approach for practitioners.

Management Workshops: Fire and Water

We convened two workshops with managers and experts to address the following: identify strategies for considering springs resources in fire treatments, meeting post-fire restoration needs utilizing volunteers, coordinate agency post-fire restoration responses across jurisdictions to protect critical water resources, and identify policies and frameworks that support effective inter-jurisdictional responses.

In February 2014, we worked with the Southwest Fire Science Consortium to develop and convene *Fostering resilience in Southwestern ecosystems: A problem solving workshop*, held in Tucson, AZ. The workshop had over 150 participants from Arizona and New Mexico representing a diversity of agencies and organizations and with expertise in a wide diversity of disciplines related to fire suppression, fire management, restoration, and fish and wildlife management. Participants worked through a variety of questions in roundtable settings in order to develop implementable strategies for management and fire response that will support resilience as fire regimes continue to change. There was robust and creative strategy development around protection of refugia such as springs from fire impacts, and on re-thinking post-fire responses to include active restoration in support of sensitive water resources. Further information on the workshop results can be found here: **http://swfireconsortium.org/Fire%20and%20Resiliency%20Ecology%20Workshop/**

In November 2015, we hosted a workshop as part of the Society for Ecological Restoration Southwest Chapter conference titled *Fire Effects: Restoration of Watersheds and Springs*. The workshop was designed to provide participants with information on trends in fire effects on watersheds, streams, and springs; offer tools to respond to these impacts before and after fires; and foster a discussion on next steps for restoration practitioners. We focused discussion on how land managers and restoration practitioners can foster resilience, restore ecological function, and ease transition for ecosystems and species in the face of changing fire regimes.

The workshop had 67 participants including land and resource managers, researchers, restoration practitioners, conservation practitioners and tribal members. The format consisted of a series of 11 presentations followed by facilitated networking and small group discussions organized by topic that addressed the following questions:

- **Tools:** What restoration tools are currently working for wildfire effects?
- **Challenges**: What hasn't worked? What are some of the challenges? How are you taking climate change into account?
- **Recommendations:** What are 2-3 recommendations you have for managers and practitioners? (specific strategies/tools, research, training, new partnerships, etc.)

See Appendix D for further information on the workshop results.

Outreach

A key component of this project was continued engagement of managers to gather input, share results, and ensure that the project was progressing in a manner consistent with management and conservation needs. Throughout the project, we maintained communications and coordination with more than 30 entities that make up the informal regional springs stewardship network. We coordinated through a combination of in-person meetings, webinars, and regular email contact with the full group to update them on project progress. We also coordinated through more formal regional information sharing via meetings of the recently formed Sky Island Restoration Cooperative (Figure 12), and coordination with Chiricahua leopard frog recovery efforts.

To reach managers beyond our active regional partner group, we presented on this project at a number of broad reaching venues, including conferences focused on natural resource management and adaptation to climate change (e.g. National Adaptation Forum, Society for Ecological Restoration National and Chapter Conferences), through Desert LCC Steering Committee meetings and webinar series, through the National Conservation Training Center webinar series Safeguarding Wildlife from Climate Change, workshops, and symposia. Our presentations focused on sharing project methodologies in addition to results.

Figure 12: Members of the Sky Island Restoration Cooperative discuss restoration options and results.

Results

Random Sample Spring Inventories and Assessments

We conducted inventories at a total of 56 springs in the Upper Santa Cruz study area (Table 5). Two of the 56 sites were surveyed by Saguaro National Park Staff. Forty-one of the springs were part of the clustered random sample, 9 springs were opportunistically sampled, 1 spring was assessed as part of the Adopt-A-Spring program, and we documented 5 springs that had not previously been mapped. Of the 41 springs that were part of the random sample, 9 were unlocatable by surveyors (Table 6). Of the 9 springs that were opportunistically sampled, 3 were unlocatable by surveyors. For purposes of analysis – drawing conclusions about springs across the study area - we only analyzed the randomized sample set. Full spring inventory reports are available for all springs surveyed in this project in Appendix B and C. The project results are described below in two sections - one describing the analysis results from springs inventories and assessments and one describing overall project outcomes.

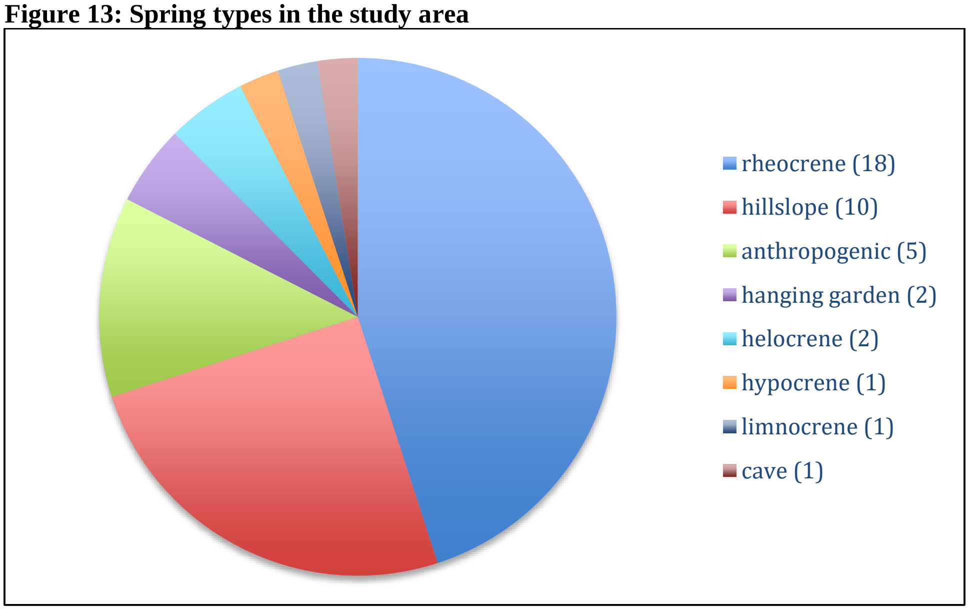
Basic Statistics Across Random-Sample Springs in Santa Cruz Basin

Springs Types: There are 12 spring types recognized (Springer and Stevens 2008). We detected 8 types of springs among the 32 we surveyed with the following order of abundance (Figure 13):

Rheocrene >> Hillslope > Anthropogenic > Hanging Garden; Helocrene > Cave; Hypocrene; Limnocrene

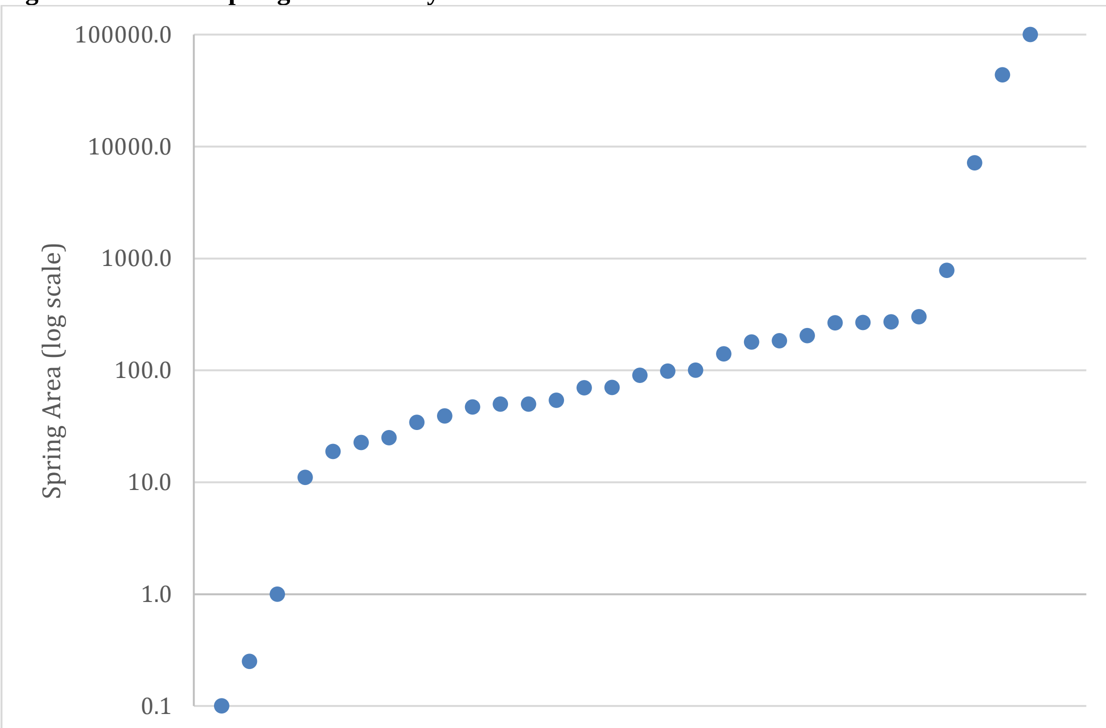
Five springs were classified as primarily or secondarily anthropogenic with another primary or secondary type because they were modified so extensively that their sphere of discharge was altered. Of the 32 randomly sampled springs successfully inventoried, 19 were developed for a development rate of 59% across the study area. Developments at springs primarily included spring boxes, constructed dams, piping to holding tanks or cattle drinkers, and accompanying devices like floats.

Figure 13: Spring types in the study area



Springs Habitat Area: Spring site area calculated from site sketch maps ranged from a low of 0.1 m^2 at Brinkley Spring to a high of 100,000 m^2 at Agua Caliente Spring, with an average spring area of 5,140 m^2 (s = 19,625). Most springs were between 10 and 100 m^2, with a median spring area of only 80 m^2 (Figure 14). The total area encompassed by springs surveyed in the Upper Santa Cruz River study area was 153,933 m^2 or 0.0024% of the (6,319,761,736 m^2) study site.

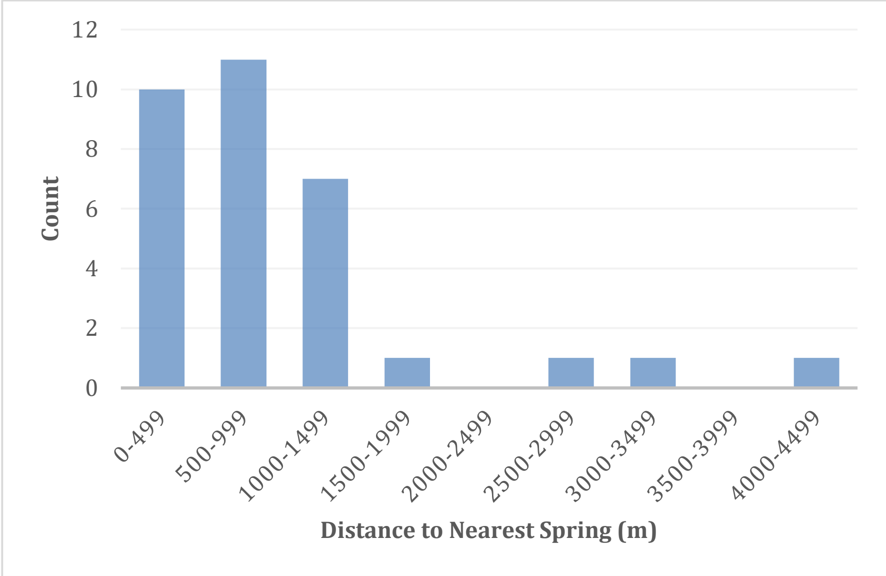
Figure 14: Area of springs in the study area.



Elevation: Elevation of spring sites ranged from a low of 822 meters at Agua Caliente Spring to a high of 2,742 meters at Cascade Spring near the peak of Mount Lemmon in the Santa Catalinas, with an average elevation of 1,888 meters.

Isolation: The distance from springs inventoried to the next nearest spring site ranged from a low of 132 meters at Rock Spring, to a high of 4,431 meters at Agua Caliente Spring with an average distance to nearest spring of 967 meters (s = 908). Most springs were within 1,500m1500m of another spring, but a small number were quite isolated (Figure 15).

Figure 15: Isolation of springs in the study area.



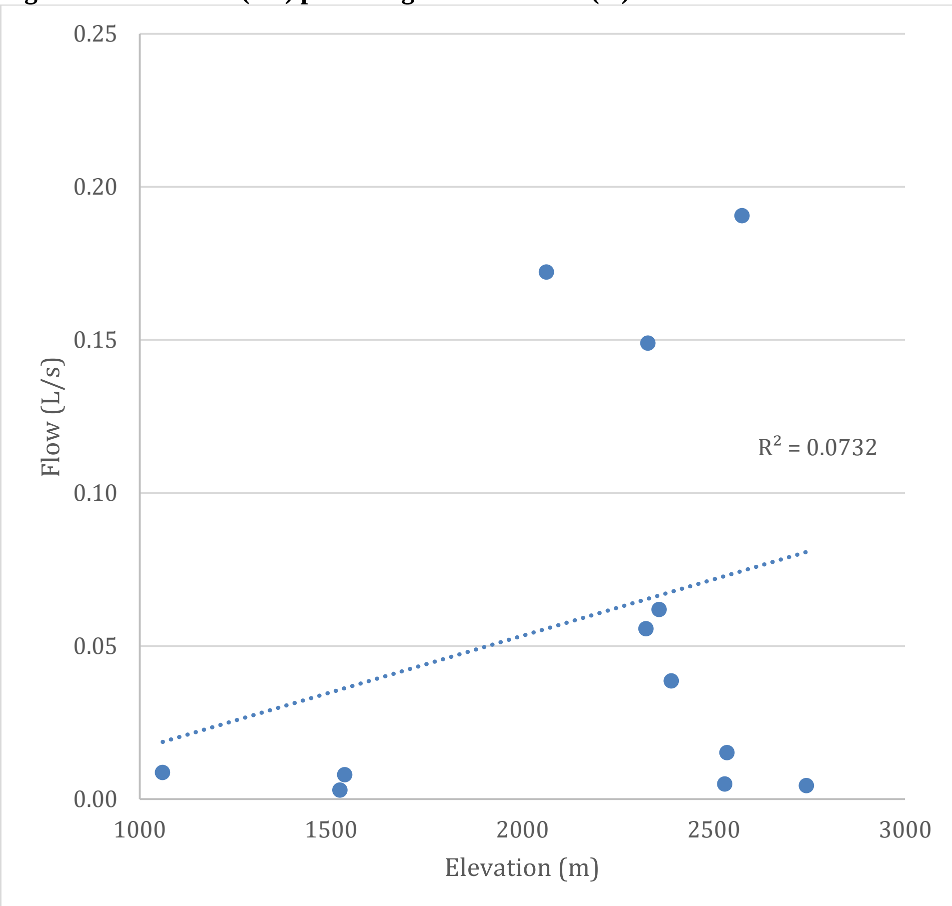
Flow: Of the 41 randomly sampled springs, surveyors were unable to locate 9, indicating they were likely dry for some extended period of time. Another three of the 41 randomly sampled springs were located and inventoried but had no water present on the site at the time of visit. Twenty-nine, or 91%, of the 32 springs sampled had some water present at the site at the time of survey (or 71% of the 41 randomly sampled springs that were searched for).

For the springs with sufficient flow present to measure, the flow rate ranged from a high of 0.2 L/s at Bellows Spring to a low of 0.003 L/s at Ruelas Spring. The flow was not measured at 13 springs at which water was present due to one of the following: pooled water or diffuse flow prevented capturing flow, the flow rate was low enough that water could not be captured for volumetric measurement (e.g. wetted soil present), or the presence of infrastructure prevented measurement. The average flow rate for the study area was 0.06 L/s (n=12). Table 3 shows average flow by spring type. Figure 16 shows the lack of a relationship between flow rate and spring type for the study area.

Table 3: Average Flow by Spring Type

Spring type	**Average Flow at Measured Springs**
Rheocrene	0.054 L/s (s = 0.070)
Hillslope	0.059 L/s (s = 0.077) (only 5 of 9 had measurable flow)
Hanging garden	No measurable flow

Figure 16: Flow rate (L/s) plotted against Elevation (m).



Water Quality: Field specific conductance ranged from a high of 1,086 ųS/cm at Crescent Spring to a low of 42 ųS/cm at Cascade Spring with an average of 347 ųS/cm (n=18, *s*=343). Generally, specific conductance decreased with increasing elevation (Figure 17). Specific conductance was lowest in the Santa Catalina and Rincon Mountains, and highest in the Patagonia and northern Santa Rita mountains.

PH ranged from a low of 6.4 at Ranger Station Unnamed spring, an undeveloped high-elevation spring, to a high of 8.6 at Red Spring, an undeveloped mid-elevation rheocrene spring, with an average of 7.3 (n=19, *s*=0.56). PH had no relationship with elevation (Figure 17) or mountain range.

Water temperature ranged from a low of 5.95 C at Bellows Spring, an undeveloped high-elevation spring, to a high of 27.9 C at Red Spring, an undeveloped mid-elevation rheocrene spring, with an average of 7.3 C (n=19, *s*=0.56). Generally, water temperature decreased with increasing elevation (Figure 17). See Table 4 for more detailed information on water quality by mountain range.

Figure 17: Water quality versus elevation of springs in the study area.

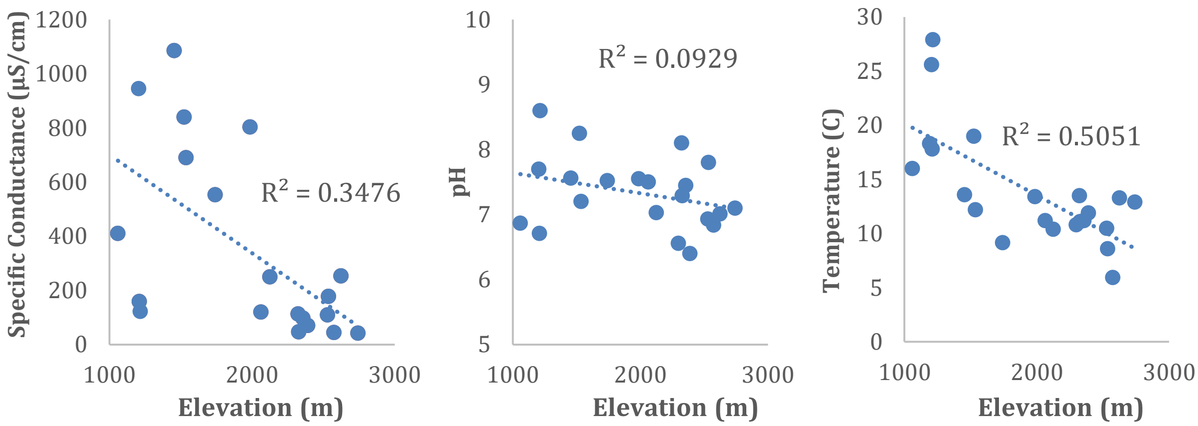


Table 4: Water quality of springs across mountain range in the study area, including specific conductance (SC), pH, and temperature (T).

Range	*SC*	*pH*	*T*
Atascosas	409	7.7	23.8
Catalinas	124	7.3	11.7
Patagonias	1086	7.6	13.6
Rincons	228	6.9	14.1
SR N	765	7.7	15.6
SR W	354	7.3	10.0

Flora and Fauna: The flora and fauna analysis is limited by the constraint of spring survey teams having varying plant and animal identification skill sets. Also springs across the study area were visited at different times of the year. Thus, the plant and animal species lists provide an initial snapshot of diversity present at each spring.

We collected 808 plant records at surveyed springs (262 were collected by Saguaro NP), including 231 species identified to the species level, 85 species identified to the genus level, and 4 species identified to a higher taxonomic level. Of these, 21 species were identified as invasive. There were 56 plant records listed as unknown.

We collected invertebrate observations at 24 springs and recorded an array of invertebrates. We recorded 21 orders of invertebrates. The greatest number of invertebrate families recorded at a single spring was recorded at La Cebadilla Cienega. The most commonly recorded families of invertebrates at springs were Dytiscidae, predacious diving beetles; Apidae, bees; Pieridae, white and sulphur butterflies; Hesperiidae, skipper butterflies; Nymphalidae, brush-footed butterflies; Vespidae, wasps; Lycaenidae, gossamer-winged butterflies; Papilionidae, swallowtail butterflies; Erotylidae, pleasing fungus beetles; Formicidae, ants; and Notonectidae, water boatmen.

We collected vertebrate observations at 29 springs. We observed 102 species of vertebrates: 12 species of reptiles and amphibians, including Chiricahua leopard frog; 15

mammal species, 1 fish species, the invasive mosquito fish; and 74 bird species. The greatest number of vertebrate species recorded at a single spring was recorded at Caseco Spring. The most commonly recorded vertebrates were:

Deer > Yellow-eyed Junco > House Wren, Western Tanager > American Robin, Spotted Towhee

Table 5: Springs at which inventories were conducted in the Upper Santa Cruz River study area including date, area, spring type, elevation, coordinates, and whether they were new, opportunistic, or part of the random sample. Springs highlighted in blue were surveyed by Saguaro National Park Staff

Site Name	Date	Area (m2)	Spring Type	Elevation (m)	UTM E	UTM N	Category
Agua Caliente Spring		100,000	limnocrene	822	525524	3571579	random sample
Alamo Spring	6/29/14	98	rheocrene	1319	486936	3470165	Adopt A Spring
Bellows Spring	11/15/14	140	rheocrene	2574	514130	3507062	random sample
Bog Springs	11/16/14	327	hillslope	1748	512966	3509573	opportunistic
Brinkley Spring	6/29/14	0.1	anthropogenic/ hanging garden	2705	519909	3588834	random sample
Broken Arm Spring	10/4/14	1	rheocrene	1319	490216	3474456	opportunistic
Busch Spring	6/13/15	54	rheocrene	2357	522547	3588814	random sample
Cascade Spring	6/29/14	47	rheocrene/ anthropogenic	2742	519810	3588992	random sample
Caseco Spring	6/28/15	179	rheocrene	2323	527703	3585599	random sample
Chiva Falls	9/3/14	970	hanging garden	1204	538097	3569127	newly mapped
Crescent Spring	4/20/14	204	hanging garden/ anthropogenic	1454	523562	3471702	random sample
Deering Spring	8/9/15	no map	rheocrene/ anthropogenic	1726	522612	3519274	opportunistic
Devil's Bathtub Spring	9/14/14	183	rheocrene	2328	542852	3562298	random sample
Flicker Spring	6/28/14	90	rheocrene/ hillslope	2624	520863	3589684	random sample
Florida Spring	11/15/14	23	rheocrene	2125	515331	3510509	random sample
Gibbon Springs	9/11/15	7130	helocrene/ hypocrene	859	521335	3574177	random sample
Huntsman Spring	6/13/15	no map	rheocrene	2462	522662	3587823	random sample
Iron Spring	2/7/15	150	rheocrene	1762	509056	3504223	opportunistic
Italian Spring	9/13/14	39	rheocrene	2298	543728	3565922	random sample
Jackalo Mine Spring	4/19/14	185	anthropogenic	1659	524011	3474354	newly mapped
Kent Spring	11/16/14	70	hillslope	2063	513627	3508574	random sample
Kinglet Spring	6/28/14	50	hillslope	2535	520821	3590007	random sample
La Cebadilla Cienega	4/22/12	43,695	helocrene	826	529348	3567583	random sample
Mercer Spring	6/28/15	70	rheocrene	1371	527928	3577772	random sample
Mine Shaft unnamed north	10/5/14	100	rheocrene	1257	490123	3470905	opportunistic
Observatory unnamed	6/14/15	25	rheocrene	2529	525612	3586512	random sample

Ojo Blanco Spring	11/14/15	301	rheocrene/ hillslope	1536	526996	3528674	random sample
Palisade RS Unnamed	6/14/15	11	rheocrene	2440	526855	3586061	random sample
Papago Spring	11/17/15	98	hillslope	1190	539259	3549577	random sample
Pena Blanca Spring *	10/4/14	268	hillslope	1209	491220	3472685	random sample
Puerto Spring	7/31/15	no map	rheocrene	1112	488593	3498918	opportunistic
Rancho Fundoshi Spring	6/12/13	1495	rheocrene	833	518963	3574681	newly mapped
Ranger Station unnamed	6/14/15	270	hillslope	2389	526797	3585486	random sample
Red Spring	7/31/15	265	rheocrene	1215	487059	3500103	random sample
Rock Spring	12/12/14	no map	rheocrene	1060	530558	3564525	random sample
Rock Water Spring	10/4/14	782	hillslope	1205	491195	3474677	random sample
Ruelas Spring	2/7/14	100	rheocrene	1523	520218	3521289	random sample
Sabino Greens Unnamed	9/11/15	1502	rheocrene	849	520202	3574313	newly mapped
Sally Spring	2/7/15	18.75	hillslope	1742	509782	3503818	random sample
Solstice Spring	12/20/14	1	rheocrene	1554	522661	3519057	random sample
Sprung Spring	11/15/14	0.25	rheocrene/ anthropogenic	1980	513205	3506803	random sample
Unnamed	11/14/15	no map	rheocrene	1347	528178	3529438	newly mapped
Vine	12/20/14	34	cave	1986	510135	3507215	random sample
Wren Spring	6/13/15	50	hillslope/ anthropogenic	2400	522416	3589421	random sample

Table 6: Springs which were unlocatable in the Upper Santa Cruz River study area including date and the purported elevation and coordinates recorded in the springs database.

Site Name	Date	Elevation (m)	UTM E	UTM N	Category
Barrel Spring	9/11/15	875	520575	3574239	random sample
Basin Spring	4/19/14	1636	522853	3476375	opportunistic
Box Spring	6/27/15	1997	522685	3585483	random sample
Breazeal Spring	6/13/15	2288	522856	3588226	random sample
D-13-12 20DCB1	7/17/15	991	486851	3571782	random sample
Ocotillo Spring	7/31/15	1161	474528	3496283	random sample
Pidgeon Spring	6/28/14	2508	521226	3589844	random sample
Proctor Spring	12/20/14	1363	518730	3519533	random sample
Shannon Spring	4/20/14	1350	522632	3472676	opportunistic
Zimmerman # 1 Spring	6/27/15	2349	522872	3590245	random sample
Zimmerman # 2 Spring	6/27/15	2349	522872	3590245	opportunistic
Zimmerman # 3 Spring	6/27/15	2449	522873	3589844	random sample

Springs Ecosystem Assessments

The Springs Ecosystem Assessment Protocol is a framework for evaluating ecological integrity of springs, overall condition of the natural resources at springs and the risks posed by human impacts. We scored the quality and risk of 33 variables at assessed springs to evaluate ecological integrity, risk, and human impacts (Table 7). Scores range from 1 to 6 (low to high) and are assigned based on a detailed scoring rubric for the 33 characteristics (see Appendix A). It is important to note that risk scores for human impacts include the consideration of how difficult it would be to restore the site by undoing the identified human impact. Scores for *natural resources condition* ranged from 0.93 at Sprung Spring to 5.24 at Palisade RS Unnamed Spring. Scores for *risks from human impacts* (natural resource risk score) ranged from 1.42 at Rock Spring to 5.5 at Sprung Spring. In general, high scores for natural resources condition corresponded with low scores for risks from human impacts. Scores for all random sample springs are presented in Table 7.

Table 7 Springs Ecosystem Assessment Overall Natural Resource Condition and Risk Scores for Random Sample Springs

Spring Name	Aquifer Functionality Water Quality Score	Aquifer Functionality Water Quality Risk	Geomorphology Score	Geomorphology Risk Score	Habitat Score	Habitat Risk Score	Biotic Integrity Score	Biotic Integrity Risk Score	Freedom from Human Influences Score	Freedom from Human Influences Risk Score	Natural Resource Condition Score	Natural Resource Risk Score
Bellows Spring	4.0	1.8	4.6	1.8	4.6	2.0	6.0	1.5	4.8	1.9	4.80	1.80
Brinkley Spring	6.8	4.0	1.8	4.6	3.4	3.4	5.1	1.9	4.6	2.6	4.34	3.30
Busch Spring	3.4	2.4	3.4	2.2	2.8	2.0	3.0	1.5	4.4	1.8	3.40	1.98
Cascade Spring	3.8	2.8	3.6	2.4	3.8	2.8	5.0	2.0	3.4	3.2	3.92	2.64
Caseco Spring	4.2	2.4	4.6	2.2	4.0	2.6	4.5	2.5	4.8	2.2	4.42	2.38
Crescent Spring	2.0	4.0	4.6	2.2	4.3	2.7	5.1	2.1	4.2	3.0	4.04	2.80
Devil's Bathtub Spring			2.0						5.8		3.90	n/a
Flicker Spring	4.7	2.0	5.2	1.8	4.2	2.6	5.3	1.8	5.1	1.9	4.90	2.02
Florida Spring	4.7	2.0	3.4	3.0	4.0	2.8	5.0	2.0	4.7	2.1	4.36	2.38
Gibbon Springs	0.0	6.0	3.6	3.2	3.5	4.8	2.5	5.5	3.0	4.0	2.52	4.70
Italian Spring									4.6		4.60	n/a
Kent Spring	4.4	1.8	4.5	2.5	4.5	2.5	4.7	2.7	5.0	1.6	4.62	2.22
Kinglet Spring	4.5	2.0	4.4	2.2	3.8	3.0	5.0	2.0	4.2	2.2	4.38	2.28
La Cebadilla Cienega	4.7	2.8	3.4	2.2	4.4	2.7	5.0	2.5	4.2	2.2	4.33	2.48
Mercer Spring	0.0	6.0	4.4	1.6	4.0	3.0	4.0	3.0	3.9	2.0	3.26	3.12
Observatory unnamed	4.2	2.0	4.0	2.4	4.0	2.2	4.7	2.0	4.8	2.2	4.34	2.16
Ojo Blanco Spring	4.2	3.2	4.0	2.0	4.4	2.6	4.8	2.5			4.35	2.58
Palisade RS Unnamed	5.0	2.0	5.8	2.0	4.4	2.0	5.3	2.3	5.7	1.9	5.24	2.04

Spring Name	Aquifer Functionality Water Quality Score	Aquifer Functionality Water Quality Risk	Geomorphology Score	Geomorphology Risk Score	Habitat Score	Habitat Risk Score	Biotic Integrity Score	Biotic Integrity Risk Score	Freedom from Human Influences Score	Freedom from Human Influences Risk Score	Natural Resource Condition Score	Natural Resource Risk Score
Papago Spring	6.0	2.4	2.6	2.0	3.2	2.2	4.8	2.0	4.3	1.9	4.18	2.10
Pena Blanca Spring	4.7	1.5	4.2	2.2	4.6	1.2	5.4	1.6	4.1	1.8	4.60	1.66
Ranger Station unnamed	3.8	2.4	3.6	2.8	3.5	2.5	3.8	3.0	4.0	2.6	3.74	2.66
Red Spring	3.8	2.0	4.8	2.0	4.4	2.2	5.0	2.0	4.8	1.9	4.56	2.02
Rock Spring	5.5	1.4	4.4	1.2	4.5	1.5	4.7	1.3	5.0	1.7	4.82	1.42
Rock Water Spring	3.0	2.7	3.0	2.4	3.8	2.2	4.9	2.0	3.8	2.4	3.70	2.34
Ruelas Spring	3.8	2.8	5.3	1.8	3.5	1.5			5.7	0.9	4.58	1.75
Sally Spring	5.3	1.8	5.2	1.8	3.6	2.2	4.6	2.6	5.1	1.3	4.76	1.94
Sprung Spring	1.0	4.5	0.8	6.0	1.0	6.0					0.93	5.50
Vine	5.3	1.8	4.6	2.2	3.0	2.2	3.9	2.6	4.8	2.0	4.32	2.16
Wren Spring	5.4	3.4	3.2	3.6	2.5	3.8	3.0	3.5	4.2	3.2	3.66	3.50

To understand the main impacts that are currently decreasing the integrity of springs in the study area we examined the array of human impacts on surveyed springs (Figure 18). Flow regulation and adjacent land conditions exert the most influence on springs in the Upper Santa Cruz River study area, followed closely by road, trail, and railroad impacts. To identify springs with potential for restoration actions or protective management actions and offer some prioritization of these, we plotted springs by overall natural resource condition and risk scores (Figure 19). We used resource condition value scores of 3 (moderate ecological condition/value) and human risk scores of 3 (moderate risk with moderate restoration potential) as the midpoints. Springs in the upper right hand quadrant are candidates for protection because they have high natural resource value but are at high risk from human impacts. Springs near the midpoint of the graphic are candidates for restoration activities because they have moderate natural resource values and are at moderate risk from human impacts. The actions to be taken would depend on site-specific conditions. See Table 10 Priority spring sites for restoration or active management and Table 11: Priority spring sites for protection for details on springs that emerged based on this analysis and review of on-site conditions described in the survey notes.

Figure 18: Types of human impacts on springs. High scores represent lower human impact.

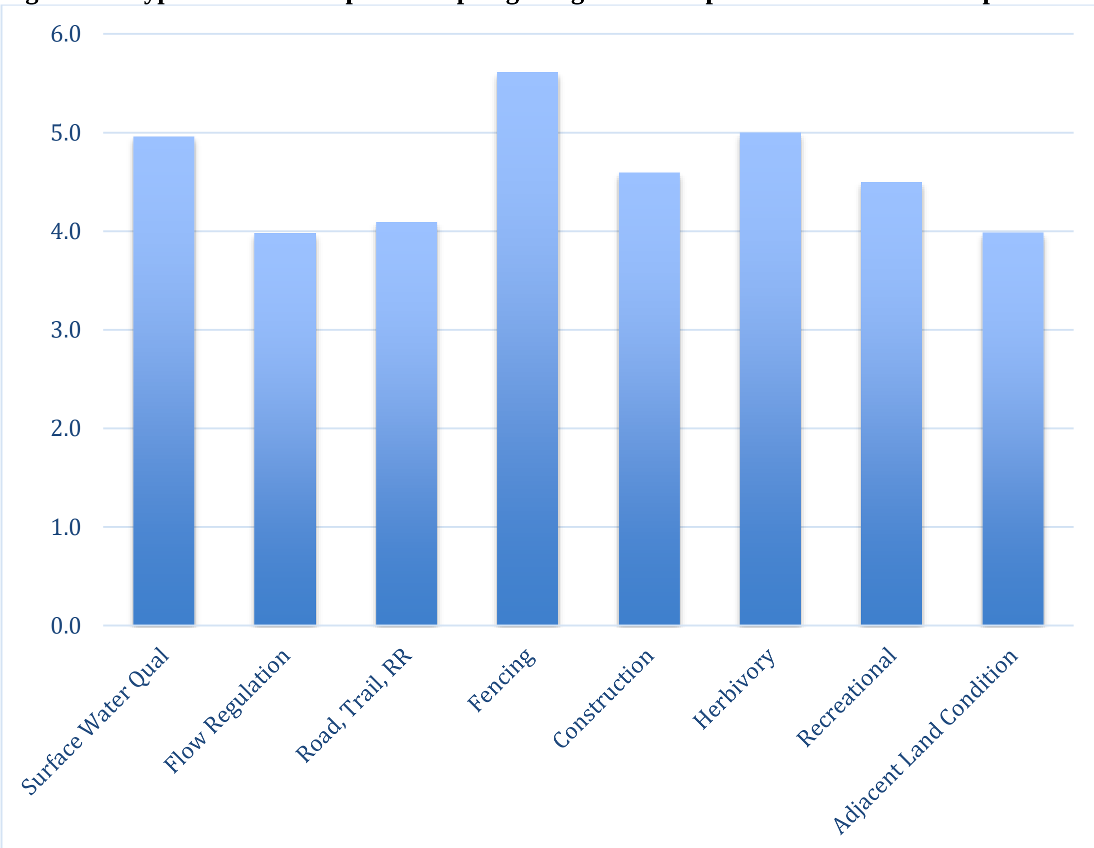
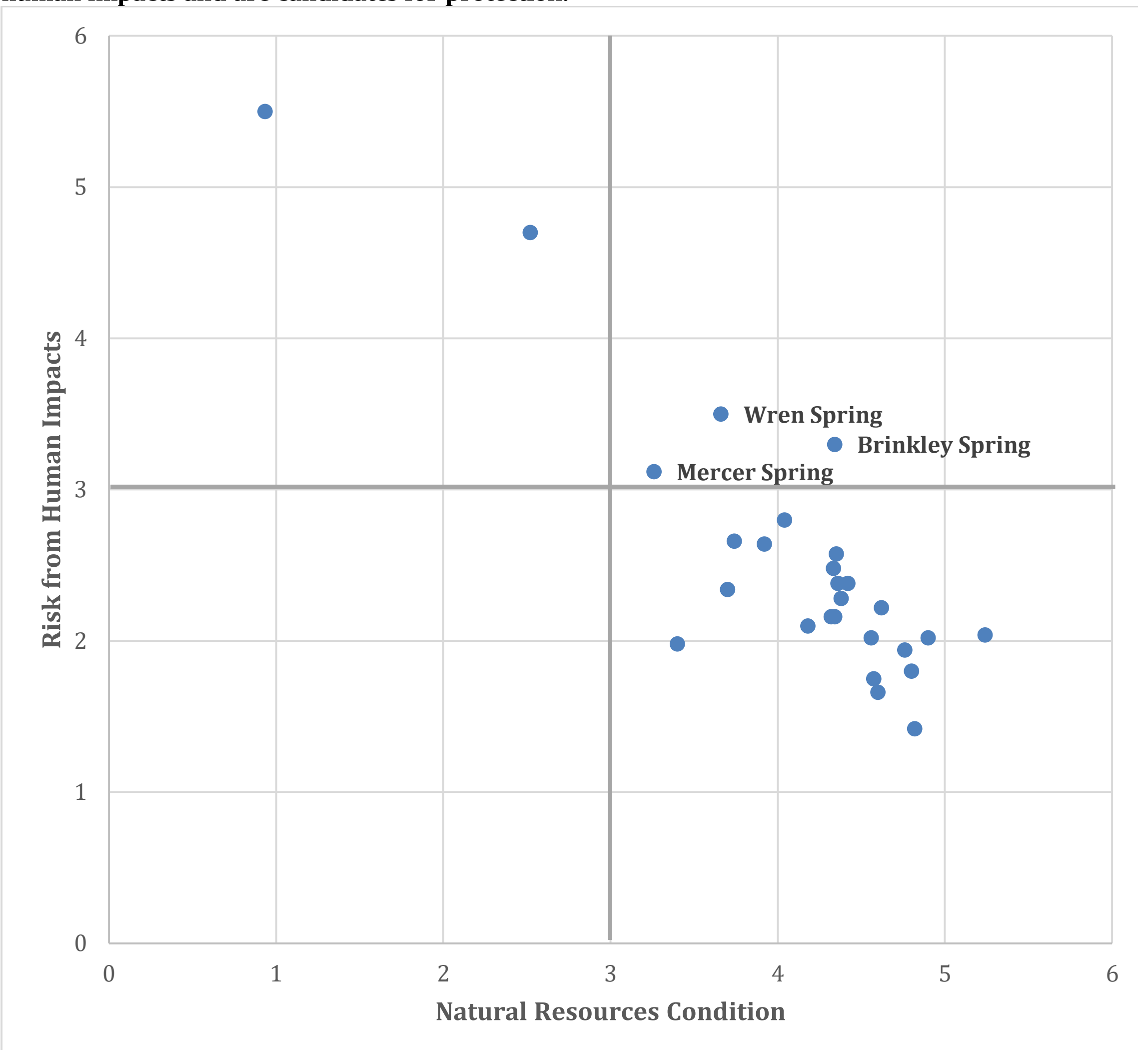


Figure 19: Stewardship risks to springs from human impacts plotted against overall natural resource condition. Springs in the upper right quadrant have high natural resource condition and high risk from human impacts and are candidates for protection.



Cataloguing Effects of Fire on Springs

We conducted inventories and assessments at 24 springs in the Pinaleño and Chiricahua Mountains on Coronado National Forest land within burned areas or the PERP. Sixteen of the random sample springs that we visited in the Santa Catalina Mountains were in fire perimeters. In the Santa Rita Mountains, we analyzed 8 springs within fire perimeters – 5 assessed opportunistically or as part of the random sample for the Upper Santa Cruz River Basin, 1 assessed as part of the Adopt-A-Spring program, and 2 assessed in the Cienega Creek Basin as part of the previous springs project (Figure 20). See Table 8 for a list of all springs analyzed in relation to fire effects and fuel treatments and Table 9 for a breakdown of spring surveys by mountain range and burn severity.

Table 8: Springs analyzed for fire or fuel treatment effects, including site name, date, spring type, elevation, coordinates, mountain range, and location. Location indicates whether the spring was in high burn severity (BS), moderate, low, very low, unburned, or in or adjacent to the PERP fuel treatment area.

Site Name	Date	Spring Type	Elevation	UTM E	UTM N	Range	Location
Box Spring	6/27/15	not found	1997	522685	3585483	Catalina	High BS
Breazeal	6/13/15	not found	2288	522856	3588226	Catalina	Low BS
Brinkley Spring	6/29/14	anthropogenic/ hanging garden	2767	519910	3588833	Catalina	Moderate BS
Bug Spring	4/22/12	rheocrene	1570	527531	3579320	Catalina	Moderate BS
Busch Spring	6/13/15	rheocrene	2357	522547	3588814	Catalina	Moderate BS
Cascade Spring	6/29/14	rheocrene/ anthropogenic	2767	519810	3588992	Catalina	Very Low BS
Caseco Spring	6/28/15	rheocrene	2323	527703	3585599	Catalina	Unburned
Flicker Spring	6/28/14	rheocrene/ hillslope	2566	520824	3589704	Catalina	Low BS
Kinglet Spring	6/28/14	hillslope	2566	520748	3589947	Catalina	Low BS
Mercer Spring	6/28/15	rheocrene	1371	527928	3577772	Catalina	Low BS
Palisade RS Unnamed	6/14/15	rheocrene	2440	526855	3586061	Catalina	Very Low BS
Pidgeon Spring	6/28/14	not found	2508	521226	3589844	Catalina	Low BS
Ranger Station unnamed	6/14/15	hillslope	2389	526797	3585486	Catalina	Moderate BS
Wren Spring	6/13/15	hillslope	2400	522416	3589421	Catalina	High BS
Zimmerman #1	6/27/13	not found	2349	522872	3590245	Catalina	High BS
Zimmerman #3	6/27/13	not found	2449	522873	3589844	Catalina	High BS
Anita Spring	5/30/15	hillslope	2837	662231	3525301	Chiricahua	Moderate BS
Ash Spring	multiple	hillslope	2150	666001	3527538	Chiricahua	Low BS
Barfoot Spring	multiple	helocrene	2409	662800	3532347	Chiricahua	High BS
Booger Spring	5/31/15	hillslope/ rheocrene	2936	662511	3526935	Chiricahua	Moderate BS
Cima Creek Spring	5/31/15	rheocrene/ hillslope	2764	662331	3526357	Chiricahua	Low BS
Deer Spring	5/30/15	hillslope	2761	663670	3523549	Chiricahua	Low BS
Eagle Spring	5/30/15	hillslope	2845	662832	3523550	Chiricahua	Low BS
Headquarters Spring	5/29/15	hillslope	2818	662306	3524561	Chiricahua	Low BS
Juniper Spring	5/30/15	hillslope	2796	663085	3523289	Chiricahua	Low BS
Lone Juniper	5/30/15	not found	2738	663485	3522626	Chiricahua	Low BS
Lower Rustler Spring	7/22/13	hillslope	2566	662832	3531315	Chiricahua	Moderate BS
Ojo Agua Fria	5/29/15	hillslope	2722	662760	3524353	Chiricahua	Moderate BS
Upper Rustler Spring	7/22/13	hillslope	2578	662586	3530995	Chiricahua	High BS
Bearwallow Spring	8/9/13	rheocrene	3145	605210	3618749	Pinaleño	Moderate BS
Emerald Spring	8/9/13	helocrene	3021	604450	3618829	Pinaleño	Low BS
Hairpin Spring Unnamed	8/3/13	rheocrene	2816	606498	3614309	Pinaleño	PERP adjacent
Heliograph Spring	8/3/13	hillslope	2760	607245	3613504	Pinaleño	PERP adjacent
High Peak Cienega	8/9/13	hillslope/ helocrene	3142	606147	3617915	Pinaleño	Moderate BS

Middle Treasure Park Spring Unnamed	8/4/13	helocrene	2733	605790	3614327	Pinaleño	PERP adjacent
Shannon Campground Unnamed	8/3/13	rheocrene/ helocrene	2793	607160	3613735	Pinaleño	Moderate BS
Snow Flat Unnamed	8/3/13	helocrene/ anthropogenic	2741	606429	3613464	Pinaleño	PERP
Treasure Park Campground Unnamed	8/4/13	hillslope	2785	605957	3614622	Pinaleño	PERP adjacent
Upper Treasure Park	8/4/13	helocrene	2738	605773	3614419	Pinaleño	PERP adjacent
Western Hospital Flat	multiple	helocrene	2750	605264	3615074	Pinaleño	PERP adjacent
Aliso Spring	multiple	rheocrene	1780	518707	3511126	Santa Rita	Very Low BS
Baldy Spring	5/19/12	helocrene	2647	514615	3507093	Santa Rita	Moderate BS
Bellows Spring	11/15/14	rheocrene	2574	514130	3507062	Santa Rita	Low BS
Bog Springs	11/16/14	hillslope	1748	512966	3509573	Santa Rita	Very Low BS
Florida Spring	11/15/14	rheocrene	2125	515331	3510509	Santa Rita	Moderate BS
Kent Spring	11/16/14	hillslope	2063	513627	3508574	Santa Rita	Low BS
Sawmill Spring	5/19/12	hillslope	2133	516932	3510413	Santa Rita	Moderate BS
Sprung Spring	11/15/14	rheocrene/ anthropogenic	1980	513205	3506803	Santa Rita	Low BS

Figure 20: Springs mapped within fire perimeters by mountain range.

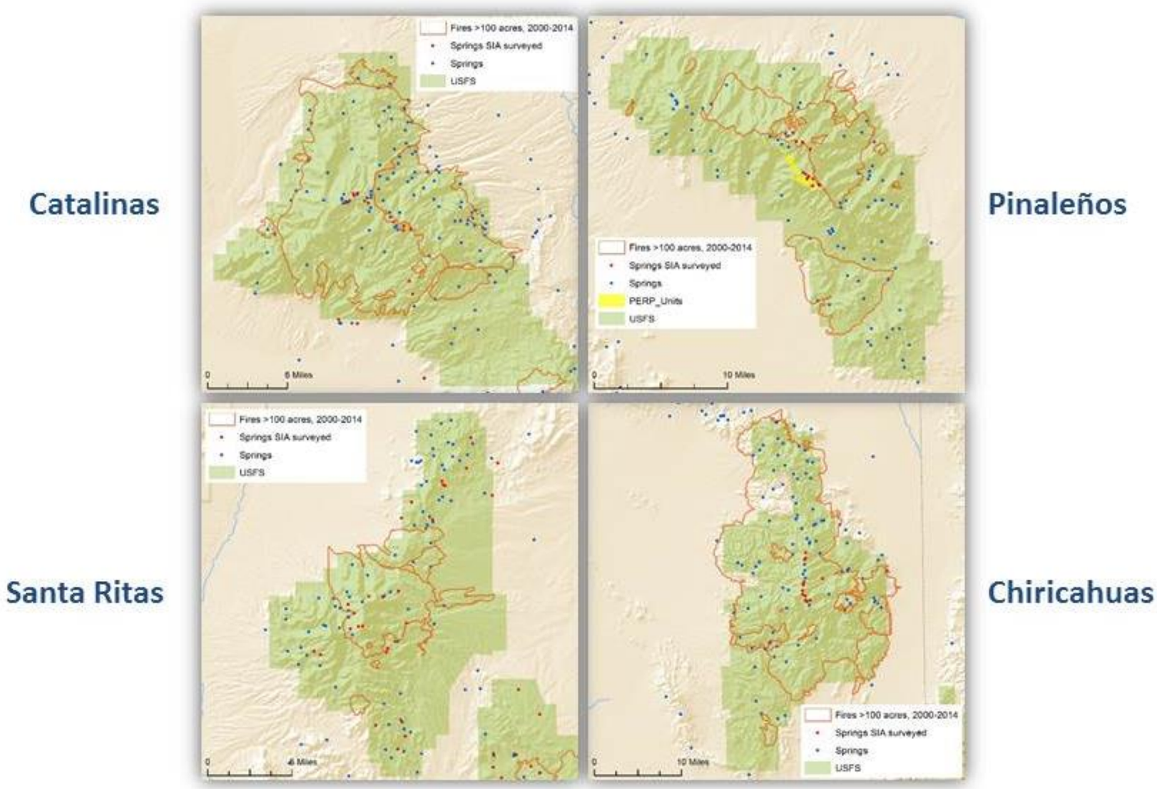


Table 9: Spring surveys conducted within fire perimeters.

Mountain Range	Numbers of Springs Surveyed by Burn Severity Type		
	Very Low/ Low Severity	Moderate Severity	High Severity
Pinaleño	2	2	0
Chiricahua	8	3	2
Santa Rita	5	3	0
Santa Catalina	8	4	4

Condition of Fire Affected Springs

The average SEAP fire influence condition score for fire affected springs was 3.5; when unlocatable springs were included in the average with a score of 0 (fire influence has eliminated the spring), the average was only 3 (moderate negative influence). Different spring types had about the same average condition as each other. As would be expected, springs that experienced higher burn severity tended to have lower condition scores, with the burn severity in the 50 m radius having a stronger correlation than in the 250 m radius (Figure 21). Aspect had little correlation with the SEAP fire influence condition score (Figure 22).

Figure 21: SEAP Fire Influence condition score in relation to burn severity.

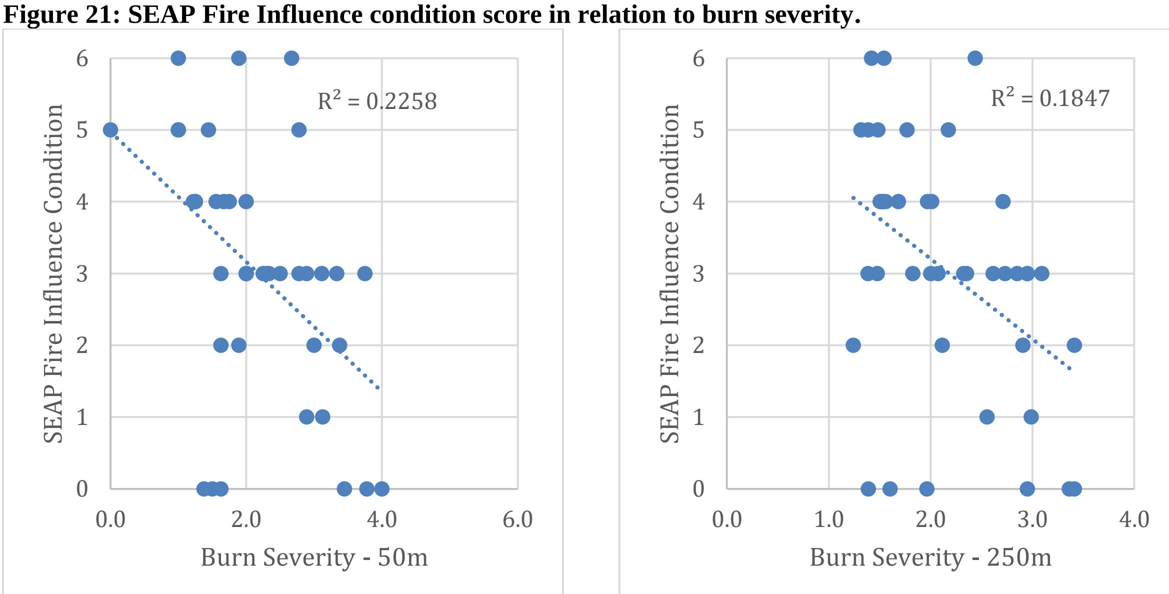
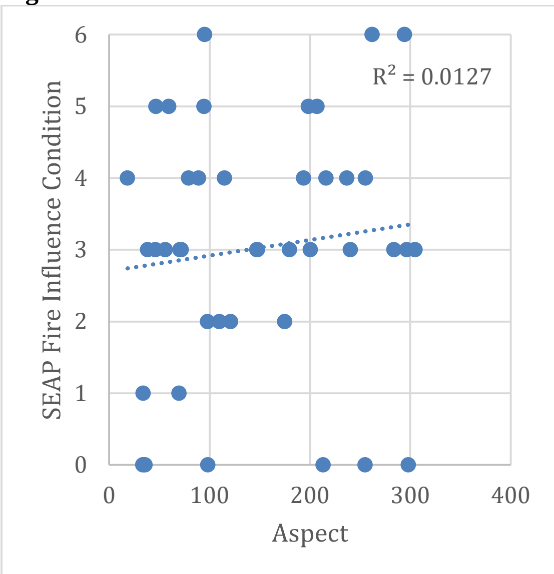


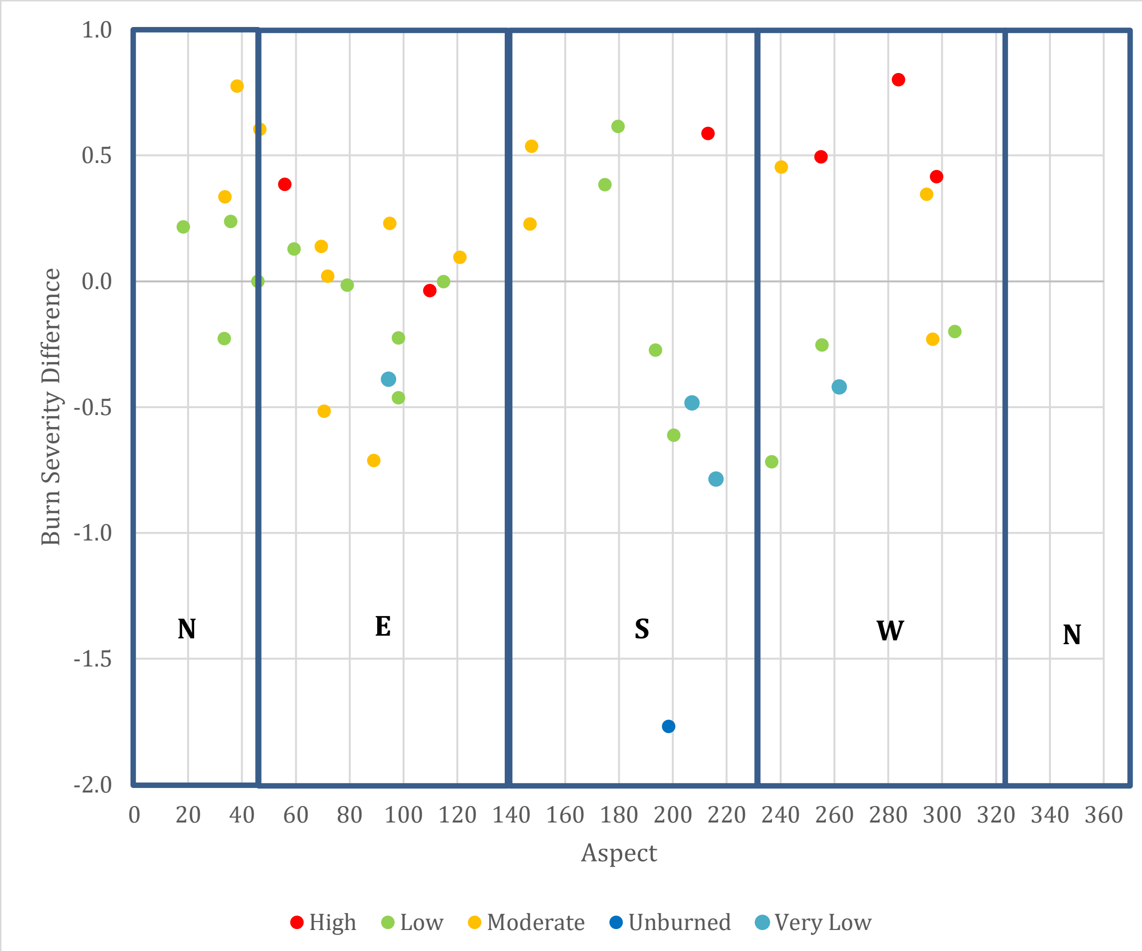
Figure 22: SEAP Fire Influence condition score in relation to aspect.



Springs as Fire Refugia

Because springs have cooler, moister microclimates, they could potentially be less affected by fire than their surroundings. However, the average difference in burn severity between the 50 m radius area around springs and the 250 m radius area was -0.008 (very slightly lower burn severity closer to springs). Sixteen springs experienced lower burn severity than their surroundings, 5 had the same severity, and 20 experienced higher burn severity than their surroundings. Across spring types, there were about the same number of springs that experienced lower burn severity as those that experienced higher burn severity, and the average difference was always less than 0.2. Aspect had no strong effect on burn severity difference, but there were some discernable patterns (Figure 23). Burn severity was always lower near the spring when burn severity was very low in general, while it was generally the same or higher near the spring when burn severity was high, particularly on west-facing slopes. On east-facing slopes, springs did seem to function a bit as refugia, with lower burn severity near the spring. These patterns might miss some effects - many springs in this region tend to be quite small, so a 50 m radius may have swamped out some refugia-type effects with too much area out of the springs' influence. Also, see below for observations of springs in the Pinaleños.

Figure 23: The association between aspect and burn severity difference, by burn severity of the area within 50 m of the spring.



Observations at Fire Affected Springs

In the Pinaleño Mountains, we observed that springs with wet meadows were low burn severity islands in higher burn severity areas (Figure 24). The edges of these wet meadows were the only places spruce and fir survived or were coming back (Figure 25). When we examined burn severity at other helocrene springs, we found this pattern in the Santa Catalina and Santa Rita Mountains also.

Figure 24. Close up of surveyed springs in relation to burn severity, a) Emerald Spring, Pinaleños, b) High Peak Cienega, Pinaleños, c) Baldy Spring, Santa Ritas, and d) Caseco Spring, Catalinas. Circles indicate the 50m and 250m radii around the spring.

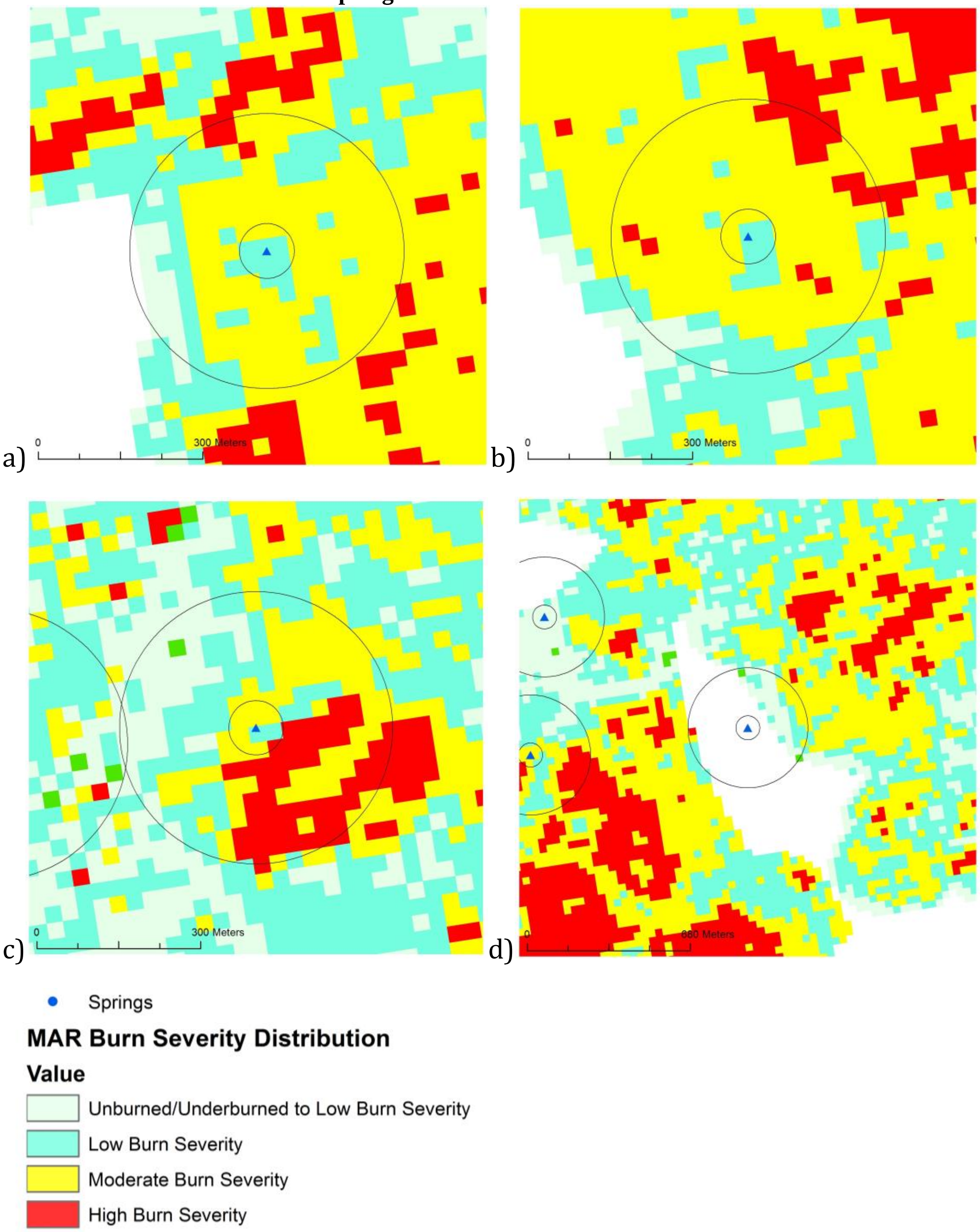


Figure 25: High Peak Cienega in the Pinaleno Mountains may be a population source for spruce and fir regeneration.

In the Chiricahua Mountains, springs in moderate and high burn severity areas had erosion problems (Figure 26 and Figure 27), and springs near Rustler Park were trampled and eroded during the post-fire cleanup process.

Figure 26: Downed trees and erosion at Anita Spring in the Chiricahua Wilderness.

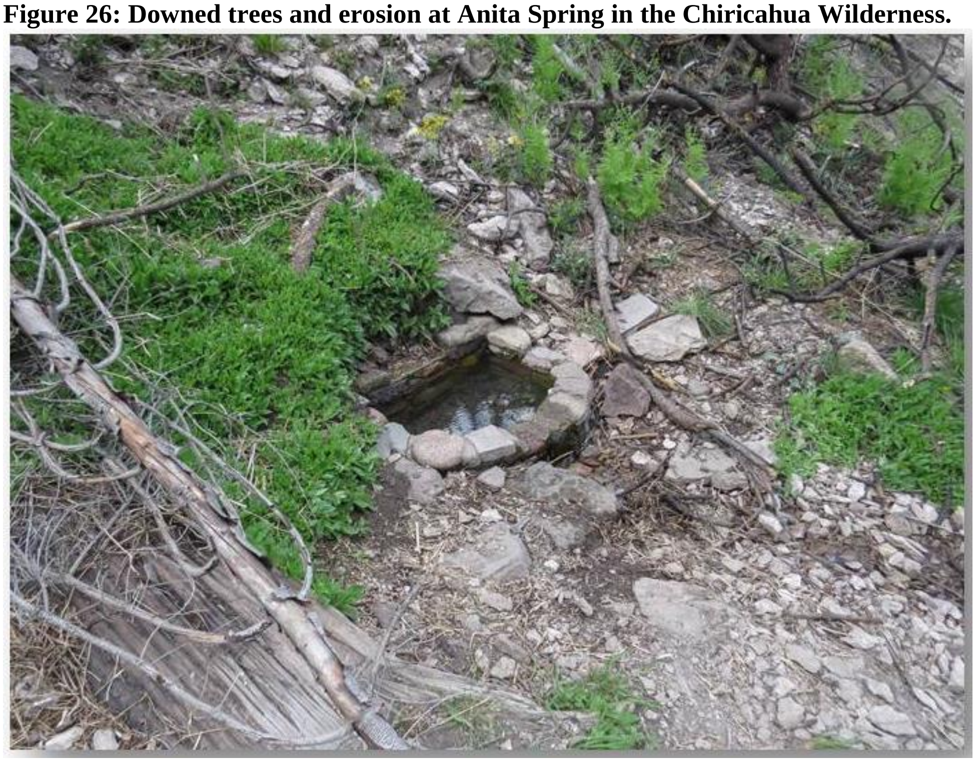


Figure 27: Severe upslope erosions and soil wasting in the Chiricahua Wilderness.

In the Santa Rita Mountains, at least one spring previously known to Forest Service to support riffle beetles was lost in the range to due severe channel erosion post-fire that obliterated the spring. Many of the springs in this range are developed.

In the Santa Catalina Mountains, three out of four springs in high burn severity areas were unlocatable; these had the three highest average burn severities within 50 m of the spring.

In every range, springs in very low and low severity burn areas were relatively unaffected by fire.

Figure 28, Figure 29, Figure 30, and Figure 31 below show the location of springs surveyed in relation to burn severity for the Pinaleño, Chirichaua, Santa Rita and Santa Catalina Mountains respectively.

Figure 28: Pinaleno Mountains - springs mapped in relation to burn severity.

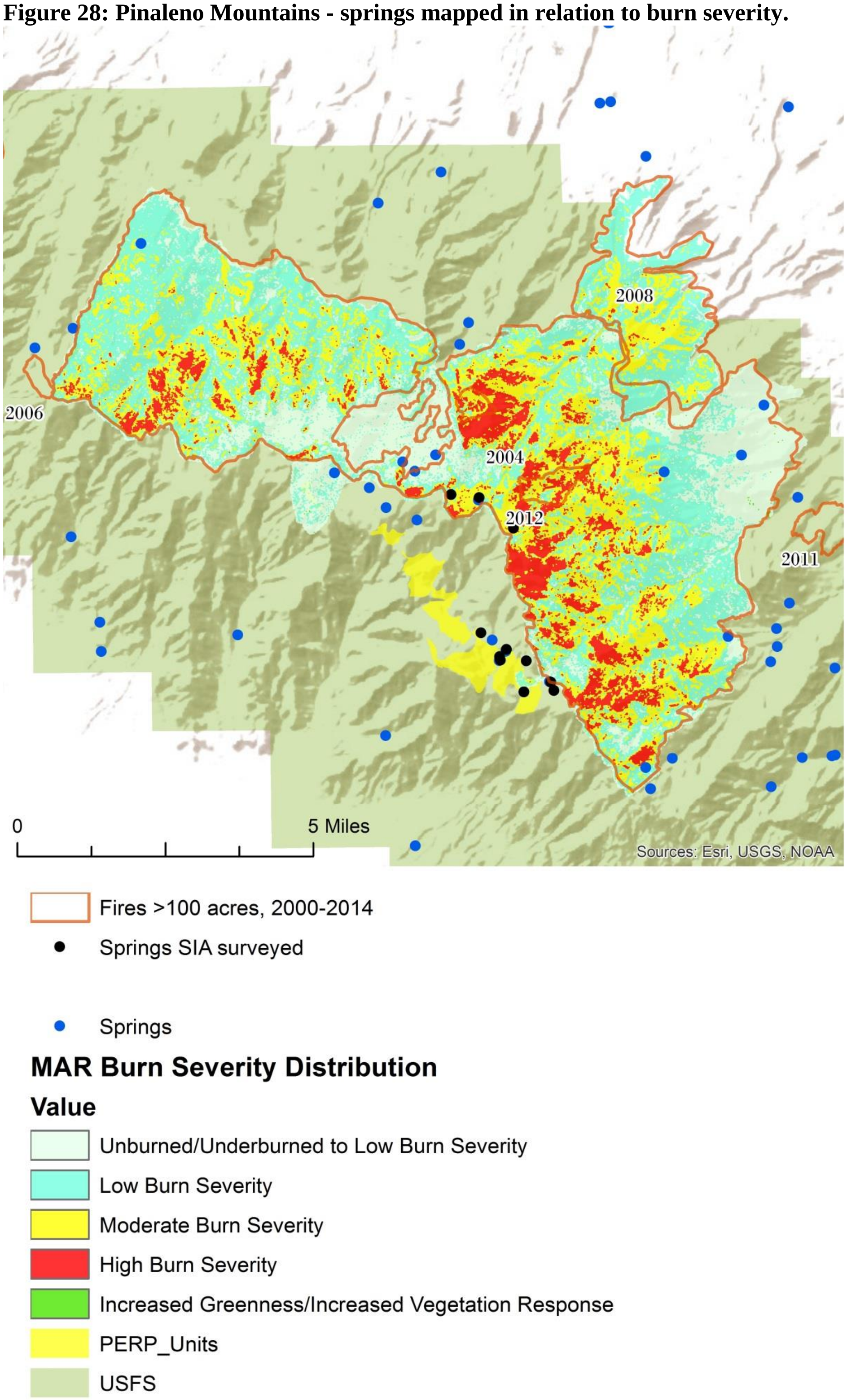


Figure 29: Chiricahua Mountains - springs mapped in relation to burn severity.

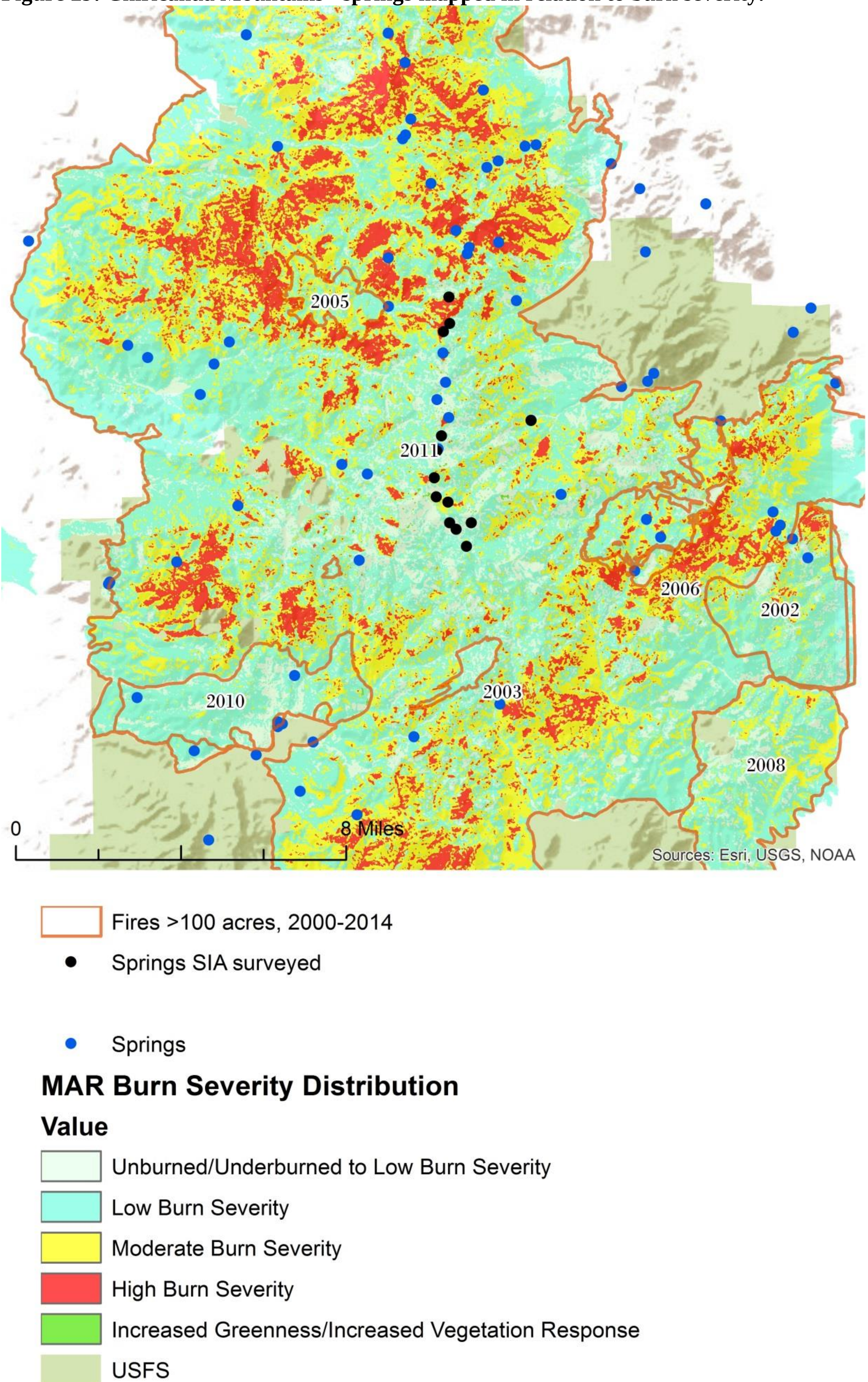


Figure 30. Santa Rita Mountains - springs mapped in relation to burn severity.

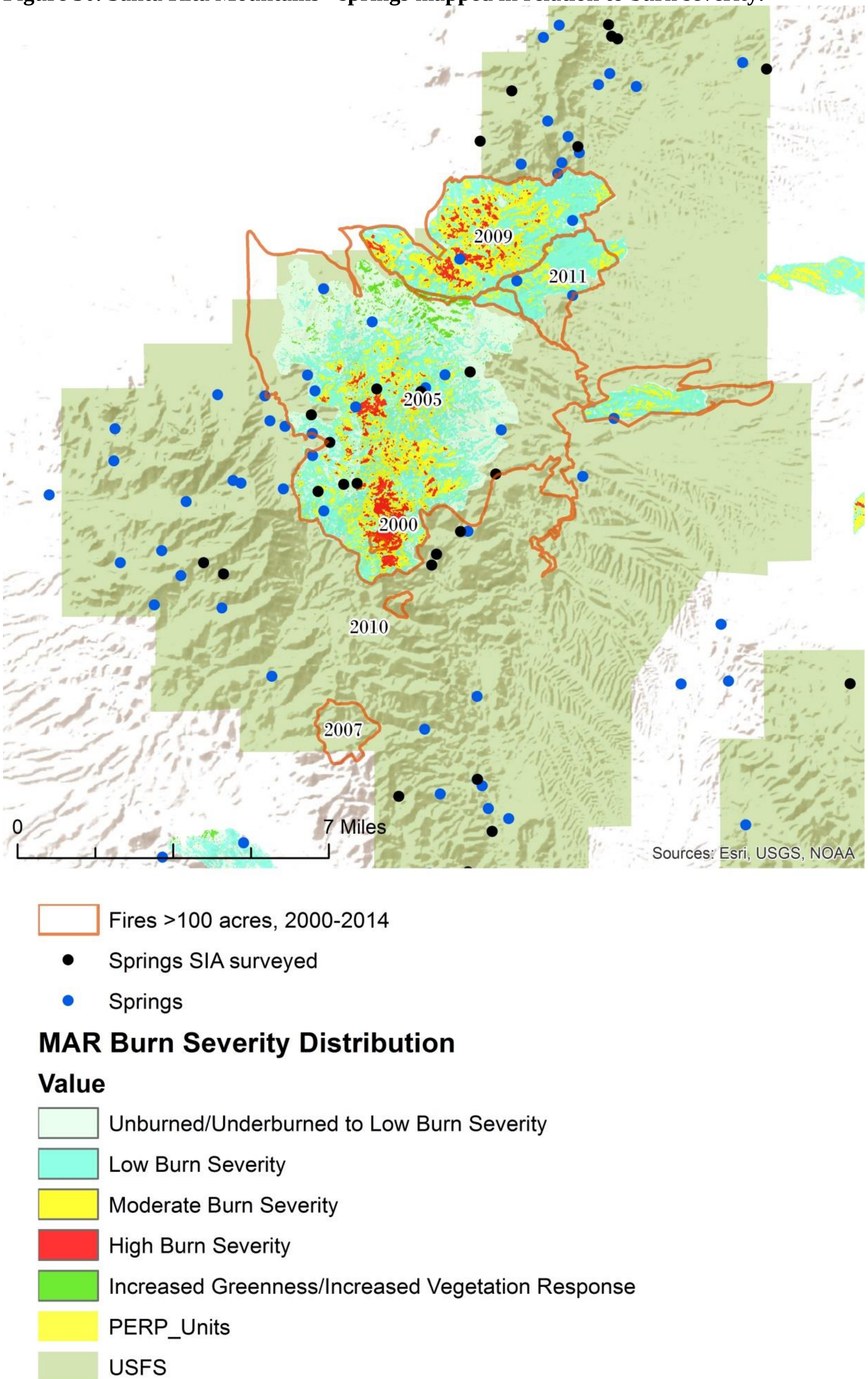
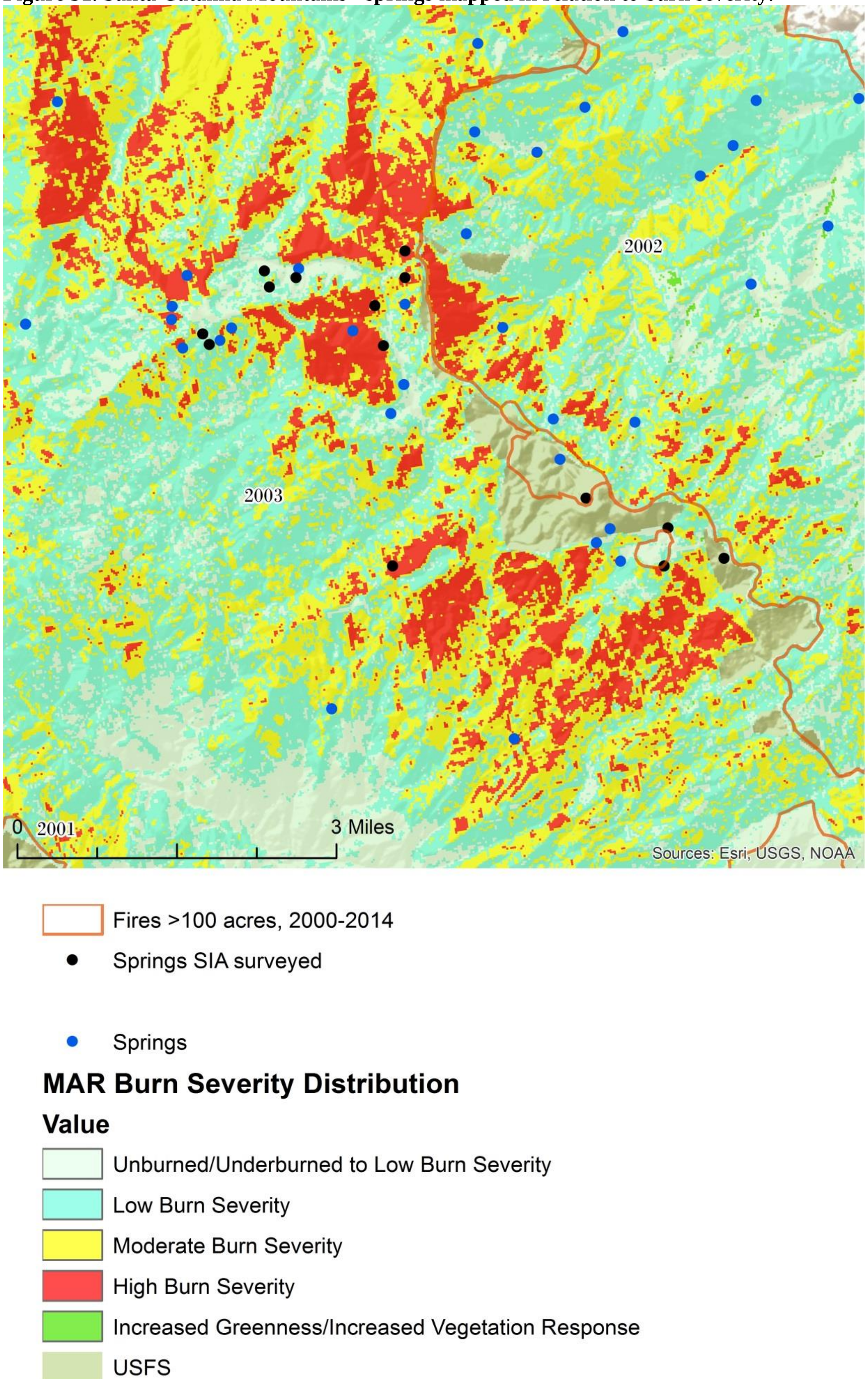


Figure 31. Santa Catalina Mountains - springs mapped in relation to burn severity.



Springs in Fuel Treatment Areas

The average SEAP fire influence condition score for springs within or adjacent to the PERP was 4.9, much higher than that of the springs in burned areas. The average SEAP fire influence risk score for these springs was 3.2, indicating moderate risk from fire.

Adopt-a-Spring Results

Since June 2014, 51 volunteers conducted 36 surveys of our 6 Adopt-a-Spring sites (Figure 32); they contributed 732 hours and 8,686 miles. Volunteers for the Botany Blitz contributed 211 hours and 1,680 miles. Once surveys were initiated at a site, all were completed, except one winter survey at each of two sites (Alamo and Ash Spring) and one dry fore-summer survey at each of two sites (Alamo and McGrew). Forty-five percent of volunteers participated in at least 2 surveys, and 33% participated in 3 or more surveys (Figure 32). All of the sites now have relatively regular volunteers monitoring them. Rock Spring is being surveyed by the Cienega Club from the University of Arizona, their watershed management club. The team leader for McGrew Spring, in Kartchner Caverns State Park, is Nikki Miscione, a park employee. We found that many, but not all, of the most committed volunteers are retirees. Some teams have been very self-directed, while others require more time to help organize and maintain. Two of the three more remote sites are monitored by couples that live close to them – Ash Spring is monitored by 1-2 couples from Portal, AZ and Alamo Spring is now monitored by a couple from Green Valley, AZ.

We completed some preliminary analysis of the data collected at Ash Spring, McGrew Spring, and Hospital Flat. At Ash Spring, flow rates appear to be highest in the spring-time and during monsoon season (Figure 33). At McGrew Spring, soil moisture in the pool and channel remains high (inundated) throughout the year, but varies in the banks and wet meadow (Figure 34). At Hospital Flat, 1.5 years has not been long enough to reveal any strong patterns in the size of the wet meadow (Figure 35).

Figure 32: Number of volunteers participating in multiple surveys for the Adopt-a-Spring pilot program.

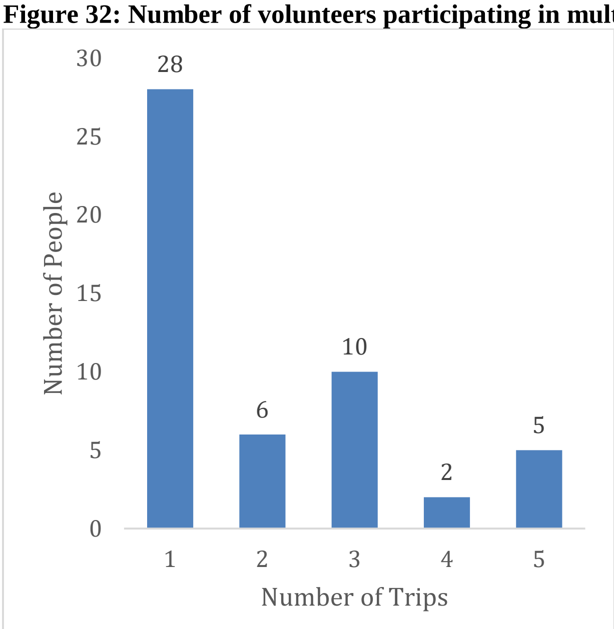


Figure 33: Flow rate at Ash Spring during the Adopt-a-Spring pilot program.

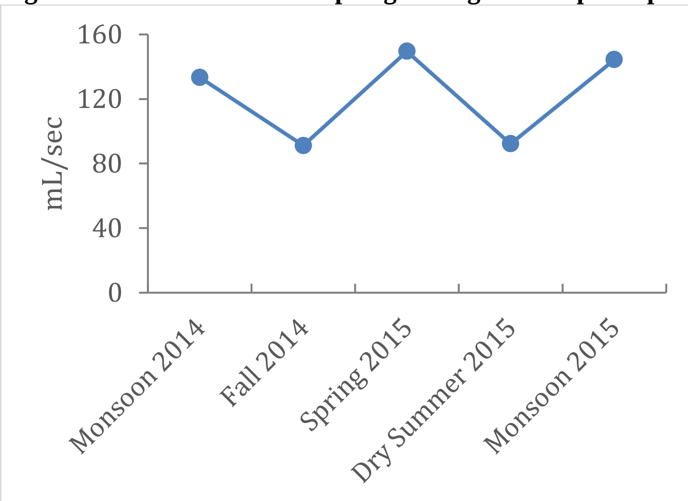


Figure 34: Soil moisture in the microhabitats at McGrew Spring during the Adopt-a-Spring pilot program. Range goes from 0 (dry) to 11 (inundated).

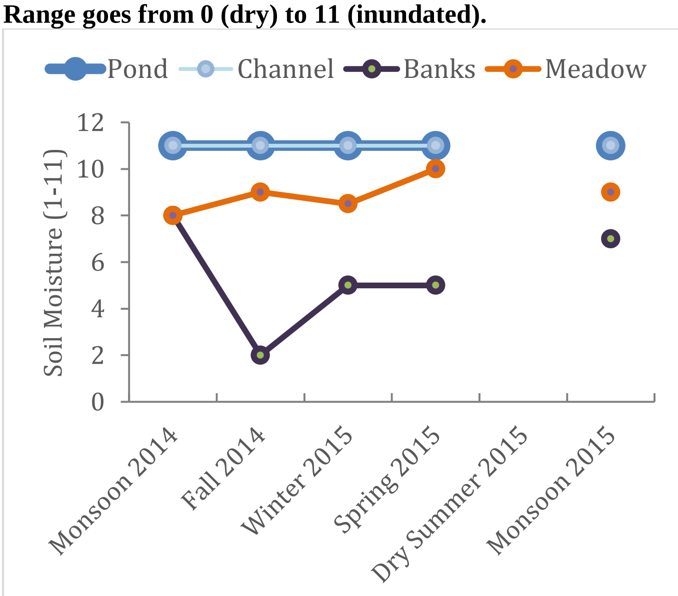


Figure 35: Size of the wet meadow at Hospital Flat during the Adopt-a-Spring pilot program. Monsoon season is highlighted by the light blue boxes.

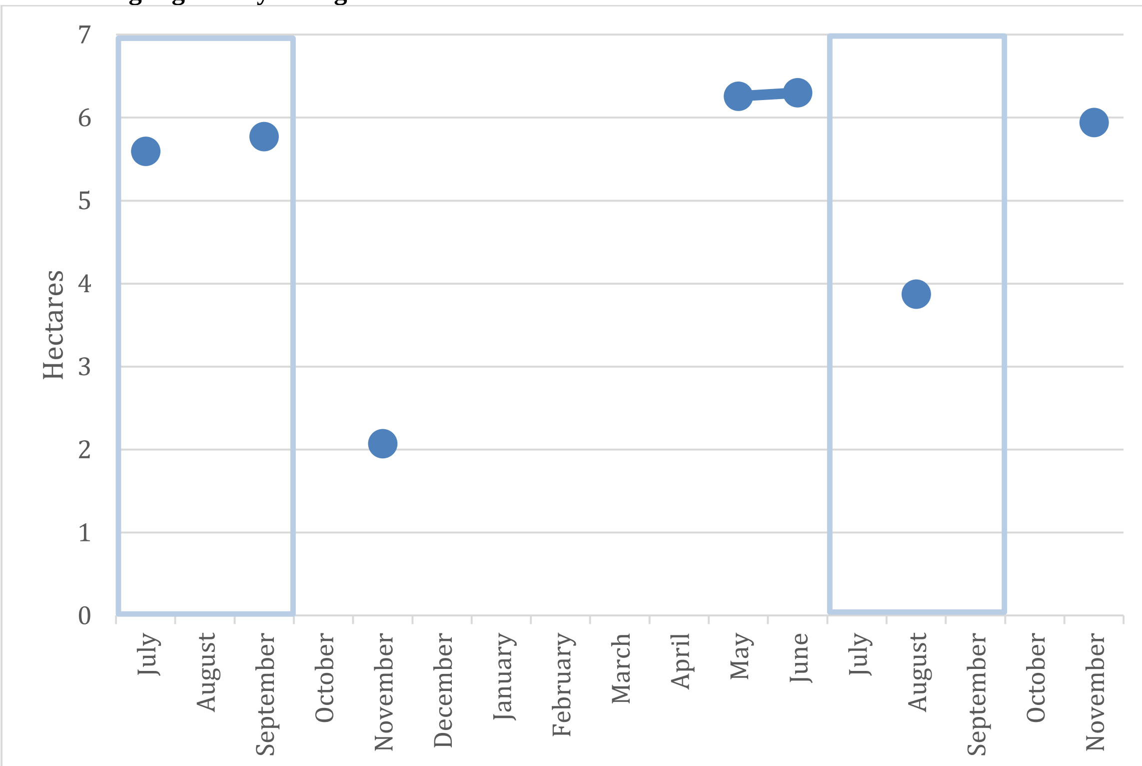


Table 10 Priority spring sites for restoration or active management

Spring Name	Recommendations
Brinkley	This high-elevation hanging garden has been nearly completely encased and conveyed underground. The area is now designated wilderness, so it may be feasible to remove the infrastructure to benefit wildlife.
Cascade	The main emergence of this high-elevaiton spring has been completely developed and now has a well casing, pump station, etc. with no spring habitat at the original site (there is some in an adjacent drainage). While the site is clearly important for human consumption, ideally a diversion of some of the water could be created to recreate the spring habitat and provide water for wildlife.
Mercer	This mid-elevation rheocrene spring was dry in June, but has riparian vegetation. It has two spring boxes – these could be removed to let the water be used naturally by the flora and fauna. It is at some risk from humans, as it is at the end of a campground and is crossed by a trail. Springs are rarer in lower elevaitons, so this spring provide a good opportunity to improve spring supported habitat.
Papago	This spring was developed for catttle in 1933 and is pumped by a windmill to a decrepit tank. While the leaking tank provides some spring-like habitat, it would be good to work with the USFS to develop a plan for this site that moved it towards a natural condition as well as other management objective.
Sprung	This spring is totally developed, and its actual source is unclear. In the last several years, its infrastructure appears to have deteriorated to the point that it is almost nonfunctional. It only provides water for wilfdlife and hikers, so it would be ideal to follow the piping back to the source, and remove the infrastructure to restore natural flow to the site.
Ranger Station Unnamed	This spring has experienced multiple stages of development, and appears to be used to provide water for a camp currently. It has many alders and appears to be a prolific, dependable spring. It is close to a road/trail and the camp, so is vulnerable to other human impacts. We recommend working with the USFS to develop a purposeful plan for this potentially very special site.

Table 11: Priority spring sites for protection

Spring Name	Recommendations
Chiva Falls	This is a hanging garden site with a waterfall in an area that is very popular with OHV users. It experiences heavy use, and there is a badly eroded, illegal road going nearly to the spring itself. The area often is heavily littered with trash. The road should be closed and restored. Protecting and restoring the site may be difficult, considering how the public is accustomed to using the site, but coould provide opportunities for engagement with a new audience.
Ojo Blanco Spring	This is a beautiful spot with many riparian trees. It is in an area that appears to have higher-than-usual spring density, and it initiates flow in a drainage that continues for several hundred meters, perhaps fed by additional springs. The spring appears to have very high water quality. It is somewhat remote and difficult to access without OHVs or horses. It is also within the range of the jaguar currently living in the Santa Ritas.

Sabino Greens Unnamed	This spring is one of the few low-elevation sites within the study area; it is one of a cluster of springs in the vicinity that appear to be related to a detachment fault at the base of the Santa Catalinas. It is undeveloped, but surrounded by a golf course and homes. There are travertine deposits that suggest it has been active for a long time.
Wren Spring	This spring has been nearly obliterated by a dirt road that bisects it. It is hard to tell its original emergence environment. We may not have found the main spring source, as it is on private land. Records indicate it may be used by humans. It may be possible to work with local landowners to improve the condition of this site.

Because springs are so heavily altered by human uses, an important benefit of springs assessments is identifying reference sites that can inform restoration and management actions in the region. Several interesting spring sites emerged as potential reference sites.

- **West Hospital Flat, helocrene**, **Pinaleño Mountains:** this site provides an excellent intact example of a high elevation wet meadow. The site is currently part of our Adopt-a-Spring program which is collecting baseline information on the site that will be useful to inform restoration.
- **Rock Spring, rheocrene, Rincon Mountains:** this is a small rheocrene site managed by the National Park Service that was once developed to provide water to a downstream tank, but has been restored by the Park Service. This site offers an example of a spring where development has been removed. Importantly, survey data exists pre-restoration, and it is being monitored long-term following restoration through the Adop-a-Spring program. This site may provide insights into how rehocrene and other springs respond when flow control infrastructure is removed.

Summary of Project Outcomes

Partner Engagement

Throughout the development and implementation of the project we worked with a diversity of natural resource management partners in the region to ensure we were building on existing work and creating project outcomes relevant to managers' needs. Through direct outreach and partner meetings, we engaged at least 60 people representing over 30 different organizations. The following organizations have been involved in the project: Arizona Game and Fish Department, Pima County, USGS, USFWS, Coronado National Forest, U.S. Forest Service Region 3, BLM-Safford Field Office and Las Cienegas National Conservation Area, Saguaro National Park, NPS Sonoran Desert Monitoring Network, Pima Association of Governments, the Desert LCC, the Sonoran Institute, The Nature Conservancy, Bat Conservation International, the University of Arizona Water Resources Research Center, Northern Arizona University, Arizona State University, EcoAdapt, the Desert Botanical Museum, and the Springs Stewardship Institute.

Springs Inventories and Monitoring

We worked with volunteers and partner organizations' staff members to inventory and ecologically assess a total of 84 springs in the Sky Island Region - 56 springs in the Upper Santa Cruz River study area, 25 springs in the Pinaleño and Chiricahua Mountains, and 3 at additional Adopt-a-Spring sites. This includes 7 springs that were not previously mapped. Volunteers contributed 1,414 hours and 6,460 miles driven.

Springs Online Database, Updates, Use and Trainings

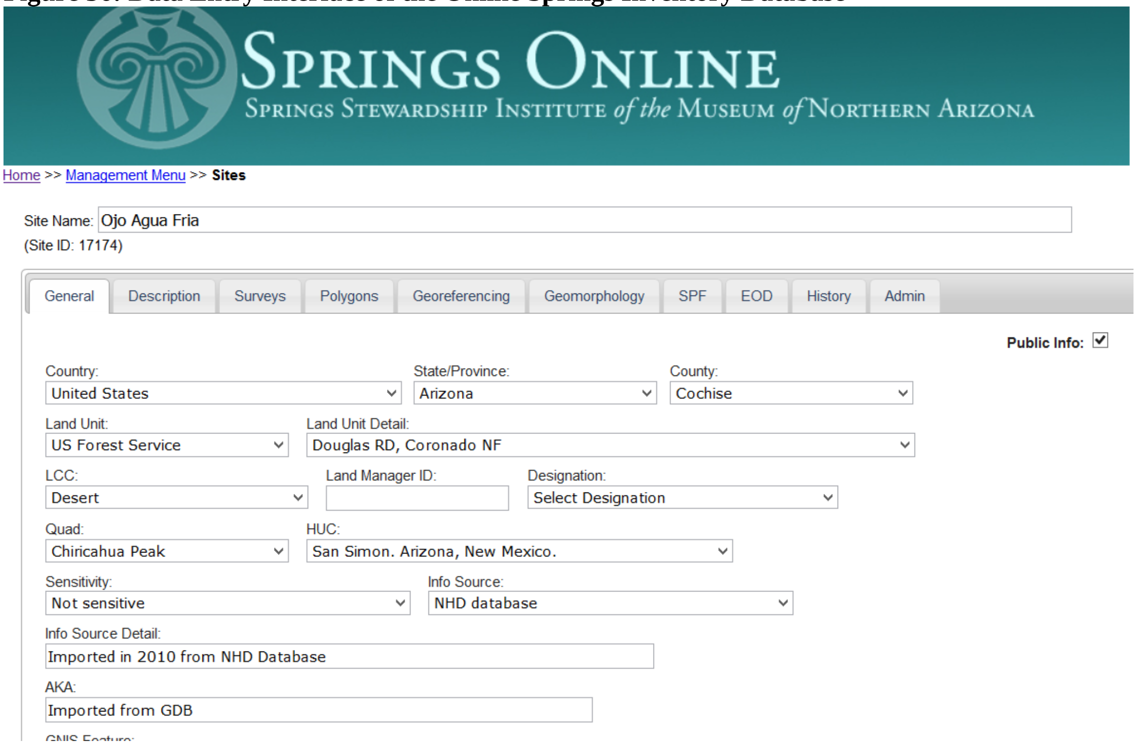
Updates and Use

The online Springs Inventory Database is available at http://springsdata.org/ and administered by the Spring Stewardship Institute. The database serves to compile information on geomorphology, soils, geology, solar radiation, flora, fauna, water quality, flow, georeferencing, cultural resources, and condition and risks, and to facilitate analysis of biological, physical, and cultural relationships. The database is an essential tool to store qualitative and quantitative information in order to facilitate documentation of present conditions, establish a baseline for future reference, inform the assessment process, guide monitoring, evaluate stewardship efforts, and monitor changes influenced by aquifer depletion climate change or other factors affecting an individual springs or many springs across a landscape (Ledbetter et al. 2010).

User permissions are administered by the Springs Stewardship Institute. Users of the database must first register and will then be given permissions to view and/or edit data according to their region, land management units of interest, projects of interest, and other relevant categories. Once users have established permissions, they can query data, enter new data real time, and download relevant springs information as csv files for use in other applications, such as a GIS. Users can also generate site-specific reports in Word or PDF format.

The Springs Inventory Database allows for the management of a wide variety of data, including general information that remains relevant for a spring regardless of when it was surveyed (locality information, a site description, microhabitat polygons, geomorphic data, solar radiation data (SPF)), a measure of data thoroughness (EOD), a history of data changes, and links to associated survey data. Survey data is collected with each visit to a spring – some springs have numerous surveys associated with them. Survey data includes a description of site conditions, surveyors present, flow statistics, water quality data, flora lists, fauna lists, Spring Ecosystem Assessment Protocol (SEAP) scores, and a measure of data quality (QAQC).

Figure 36: Data Entry Interface of the Online Springs Inventory Database



The following updates are valid at the close of 2015 and come directly from the Springs Stewardship Institute website (http://springstewardshipinstitute.org/dlcc-project-summary) (Springs Stewardship Institue, 2015):

> *Springs Online has 284 users, with new ones joining every week. These include prominent southwestern springs researchers and taxonomists, agency personnel, students, Tribal members, and independent researchers. The database has information for nearly 100,000 springs across the western United States, and over 15,000 surveys. New functions within the database include the ability to view the source of information, and whether or not the site is publicly known. This allows land managers to designate which sites are not available to the public without permission. SSI also included a sensitivity status field that allows land managers to designate whether a site's location is sensitive, survey data are sensitive, both, or neither. This structure was requested by several land managers. We also added fields for the LCC, USGS quad, and 8-digit HUC. We updated all reported springs in the DLCC with this information.*
>
> *The flora and fauna sections of the database have also been enhanced to include Springs-Dependent Species (SDS) information, including T/E species designation, spring life history, endemism, conservation status, range maps, and references. Occurrence data for reported species can be viewed on Google maps, exported as a kml file to view on Google Earth, or exported into a csv file.*
>
> *Security and permissions structures have also been enhanced, allowing project and land managers to secure sensitive information, grant access to sensitive projects or surveys, and share information with other collaborators, depending on their level of*

access permissions within the database. Security of data is of the utmost concern to SSI, as it is important to our collaborators - particularly Tribes and the National Park Service. SSI has worked closely with several Tribes to compile and archive sensitive data on reservation springs, advancing SSI's collaborative relationship with Tribal partners.

Trainings

Through this project we trained numerous springs stewards in the use of the online database and conducted broad outreach with the Spring Stewardship Institute to managers and practitioners in the Desert LCC geography to make them aware of the database. We hosted a webinar with the Springs Stewardship Institute to introduce the database to springs stewards. The recorded webinar is available here http://springstewardship.org/Videos/SkyIslandOnlineDatabaseWebinar062614.wmv We had 29 participants from a diversity of institutions including Ft. Huachuca (DOD), National Park Service, Arizona Game and Fish Department, Bureau of Reclamation, Bureau of Land Management, Defenders of Wildlife, Arizona State University and Phoenix Zoo, Amargosa Land Trust, U.S. Fish and Wildlife Service, New Mexico State Forestry, University of New Mexico, Rio Grande Research Center, Texas Tech University, U.S. Forest Service, Pima County, Arizona Land and Water Trust, and the Pima Association of Governments.

Identification of Priority Springs for Protection and Restoration: Through analysis of springs' ecological integrity assessments, we identified individual spring sites that should be priorities for protection and restoration.

New Information Available and Actively Disseminated to Springs Stewards

We estimate that we have reached hundreds of managers, conservationists, and scientists across the West that are stewarding spring resources. SIA staff gave oral presentations on the project methods and findings at the following conferences and webinars:

- **Society for Ecological Restoration Southwest and Texas Chapter Meeting (Alpine, TX):** presentation on spring surveys, planning and restoration to 150 participants
- **Desert LCC Webinar Series (online, Oct, 2014):** presentation on Springs inventory, restoration and management tools.
- **Friends of the San Pedro River General Meeting (Nov 2014):** presentation on springs assessment and restoration.
- **Society for Conservation Biology North American Congress in Missoula Montana (July 2014)**: presentation on springs project to hundreds of participants.
- **Desert Landscape Conservation Cooperative Outreach Meeting, Aguascalientes, Mexico (July 2014)**: presentation on springs inventory, management planning and restoration techniques to 70 participants.
- **"Creating Habitat for Frogs and Bats at Ash Spring" Presentation and Fieldtrip with the Arizona Native Plant Society (Sept 2014):** presentation to 35 participants and fieldtrip with 10 participants to Ash Spring.
- **National Adaptation Forum (May 2015):**

- Presentation - Responding to Climate Change Impacts in the Sky Island Region – from Planning to Action (http://www.nationaladaptationforum.org/program/symposium/few-good-ideasground-wildlife-and-ecosystem-adaptation)
- Poster - Developing Guidance for Climate-Informed Springs Ecosystem Restoration (http://www.nationaladaptationforum.org/sites/default/files/presentation_documents/Poster_67.pdf)

- **Society for Ecological Restoration Southwest Chapter Meeting (Tucson, AZ Nov 2015):** presentation on fire effects on springs and on the Arizona Spring Restoration Handbook

We also shared project methods and findings through the following publications:

- **Climate Adaptation Knowledge Exchange (October 2014):** a case study http://cakex.org/case-studies/springs-sky-island-region-inventory-protection-and-restoration
- **Sky Island Restoration Cooperative Annual Report (January 2015)** http://www.skyislandalliance.org/misc/SIRC2014/SIRC%202014%20Annual%20Report.pdf
- **SIA Communications:** This project has been regularly featured in our bi-weekly volunteer announcements and e-news communications, which reach 1,493 and 3,261 of our supporters (respectively) throughout the community.
- **Video Produced by NOAA for the US Climate Resilience Toolkit:** http://toolkit.climate.gov/taking-action/boosting-ecosystem-resilience-southwests-skyislands

Decision Support Tool Updated

With complimentary funding from the Desert LCC, the Springs Stewardship Institute updated the online mapping application that can be accessed here. This tool allows managers to quickly navigate to geographic areas of interest and view data associated with springs. The user can see three levels of spring data: unverified springs that are mapped, but their status is unknown; verified springs where the locality has been confirmed; and surveyed springs where data has been collected. Reports for surveyed springs can be viewed by clicking on the spring point and accessing the hyperlinked PDF.

Engaging Volunteers in Spring Inventories

We worked directly with the original authors of widely accepted springs inventory and assessment protocols (Stevens et al. 2012) to adapt the protocols for use with trained volunteers. Through the course of the project, we engaged 122 volunteers, many of whom were trained through inventory participation. We have had strong volunteer interest and participation in the project from the start. At the close of the project volunteers contributed a total of 2,357 hours. Volunteer engagement in the project demonstrates that this type of critical baseline data can be collected by staff-led volunteer teams, which reduces costs and time investment for partner organizations that need the information to make management decisions.

Participating volunteers have expertise in plant and animal identification, hydrology, backcountry navigation, land management, and many other disciplines. Our work demonstrates a framework for accomplishing springs inventories and assessments using trained volunteers and provides an important foundation for citizen science supported monitoring of springs in the region. Involving volunteers in this work has had the positive effect of increasing the public's knowledge of and appreciation for spring ecosystems and has created support for stewardship of these resources.

Discussion

At the start of this project agencies in the Upper Santa Cruz River study area had scattered and incomplete information about springs under their stewardship. In some cases, they knew the location of springs but had no information regarding the flow rate, species supported or potential alterations of the habitat (Misztal et al. 2012). In many cases, managers did not have access to information about springs on neighboring lands or across watersheds, limiting their ability to respond within a landscape and watershed context. In much of the region, lands managed by the USFS neighbor lands managed by BLM and counties, with watersheds and groundwater basins overlapping these jurisdictional boundaries.

Information developed through this project is now available to assist managers in understanding how their springs contribute at a landscape scale. It is also available to help managers understand how fire may have already affected springs and what to be thinking about to protect springs in the face of future fire. In the face of dramatic fire effects at springs and in surrounding lands, it New information developed through this project is being used in support of planning and decisions that address resource protection at the regional level and in climate change adaptation planning for natural resources. Examples include the Madrean Rapid Ecoregional Assessment conducted by the Bureau of Land Management and watershed restoration planning and prioritization conducted by the Coronado National Forest. By collecting more in-depth biological and hydrological information, as well as information on fire effects for known locations, we are providing a basis for understanding how environmental impacts, especially climate, are affecting these resources, and for changing management to better conserve these resources.

The random sample study design of this project provided a framework for analyzing springs characteristics and overall health at a landscape-scale. It also ensured that springs chosen for survey would not be limited to well-known, or easily accessible sites and helped us avoid favoring one agency partner over another. The nine random sample-springs we did not reach did tended to be in more remote or inaccessible areas, which may have created some bias in our results. Managers can use results from individual spring inventories to determine which priority springs are in need of immediate conservation and restoration actions. For example, Sky Island Alliance worked with the Coronado National Forest and other partners to conduct restoration at nine sites in the region already been looking at priority springs for restoration Table 10 and worked with the FROG Project to conduct restoration actions at Cottonwood Spring, including transplanting native aquatic vegetation for Chiricahua leopard frog habitat. As more data is collected on springs in different study areas of the Sky Island region, it will be possible to compare water quality, flow, and other parameters across study areas. This type of comparison will further inform management and improve understanding of the relationship between springs and their underlying hydrogeology.

This project will enhance long-term management and monitoring of springs ecosystems through application of methodologies for conducting inventories in which to train volunteers and to engage them for the long run. These methodologies and trained citizens are a strong foundation for expansion of this project and for on-going collection of data at established sites.

Given the median spring ecosystem habitat area of 80 m^2 and average habitat area of 5,140 m^2, we can expect that the 274 mapped springs in the Upper Santa Cruz River study area encompass between 21,120 – 1,408,360 m^2 or 0.0003 - 0.0223% of the entire area. Yet springs in this region have initially been documented as supporting at least 231 plant species and 102 vertebrate species. Collection of plant data was constrained by a limited number of survey team members with plant identification skills, as well as some surveys being conducted during dormant periods. Collection of vertebrate and invertebrate data was also constrained by a limited number of survey team members with identification skills. There are certainly many more plant and animal species supported by springs sites in the Upper Santa Cruz River study area than were recorded through this project. However, the results of this project provide an initial sample of plant and animal diversity at these sites. This snapshot indicates that springs in the Sky Island Region are botanically rich and support high faunal diversity compared to surrounding areas.

Sky Island Region encompasses hydrologic areas that have similar characteristics to the Upper Santa Cruz study area examined by this project. In other areas, landownership is a similar patchwork of Forest Service (dominating higher elevations), Bureau of Land Management, State, Private and local jurisdiction lands with varying degrees of access and human use. Although each hydrologic area has unique qualities and circumstances, we would expect approximately the same level of human impacts and the same types of impacts to be occurring at springs throughout the region.

Lessons Learned

Querying managers to understand their information needs and management objectives before constructing this project proposal was key to its success. It ensured we were developing the right level of information and focusing our efforts on the right outcomes. Continued coordination with partners throughout the project has also been key to its success. This type of coordination has led to changes in approaches to management as more creative energy is focused on identifying and solving management challenges associated with springs. Springs ecosystems have risen to the forefront of conversations in the region in relation to wildlife adaptation to climate change, amphibian management, watershed restoration efforts, management planning, and other topics.

Volunteer surveyors were a critical component of this project. We would not have been able to complete the extensive field work without a corps of trained volunteers. This project demonstrates that in times of decreased agency resources, properly trained and led volunteers are a valuable workforce for gathering baseline information on springs. A key consideration in using volunteers as the primary work force is data quality control and protocol compliance. Because of this, we recommend that volunteer teams always be accompanied by a staff professional formally trained in assessment protocols.

Volunteer recruitment and maintenance were critical to this project. We found that planning field work to travel to high elevations sites in the summer and low elevation sites in the winter is most effective for volunteer participation. We found engaging volunteers in springs inventories to be an excellent avenue for educating the public on the importance of these waters. Our volunteer engagement model is building a community of local citizens that have an interest in understanding and stewarding springs ecosystems, and may be a powerful voice for conservation measures that will require public support.

Our pilot Adopt-a-Spring program demonstrated that using volunteers is a viable way to monitor springs. We were able to recruit volunteers to monitor even the more remote sites that required longer or off-trail hikes, or longer drives. We did find that the sites farther from Tucson were more easily monitored with volunteers who lived closer to the site, so recruiting volunteers outside of Tucson may be important for continuing and expanding this project. Also, some volunteers are ready to move onto other types of work after one year monitoring a site; it seems as if the best approach may be to hold once- or twice-yearly trainings to recruit new volunteers, and to ask volunteers for just a one year commitment to the project. This project has revealed how dynamic many springs are, with changes through the year in flow, microhabitat size, and soil moisture.

The randomized sample design was necessary to develop information on springs that could be generalized to the full study area. This framework was important to ensure that springs inventories were not limited to well-known and/or easily accessible sites, but covered a diversity of springs.

This project offered a limited first look at fire effects at springs. To better understand these effects it is important to continue to collect assessment information at springs before they burn as well as after they burn. There is still much to be learned about the role of springs as climate refugia within burn areas, as well as how fire are affecting springs.

Management Recommendations

Ecosystem functioning of springs in the study area was most disrupted by flow regulation and adjacent land conditions, followed closely by road, trail, and railroad impacts.

Management options to address flow regulation include:

- maintaining current infrastructure so that water is not wasted or lost;
- removing infrastructure that is no longer in use to allow water to support wetted habitat;

- modifying flow regulation structures so that water is available to wildlife in addition to the use it is regulated for; and
- splitting flow regulation or otherwise putting some water onto the land to support wetted habitat while still keeping some water regulated for the intended use

Management options to address adjacent land conditions include:

- active post-fire restoration to address erosion due to fire;
- modification of grazing in adjacent lands to allow for vegetation re-growth and diversification;
- decreasing erosion associated with trampling; and
- other watershed management actions to maintain and restore healthy landscapes that will decrease threats of erosions and increase infiltration of water
- addressing adjacent land conditions to prevent catastrophic fire and other erosion-causing events.

Many of the above described management options are within the reach of land managers in the Sky Island Region. They can be implemented through other initiatives occurring in the region. Key initiatives include district-wide watershed restoration activities, FireScape and the Pinaleño Ecosystem Restoration Project currently being led by the Coronado National Forest, endangered species recovery for the Chiricahua leopard frog being led by the AZGF and USFWS, and landscape restoration efforts being led by the BLM. The Coronado National Forest is currently revising its Land and Resource Management Plan, which provides an opportunity to begin codifying special protections for springs that are in moderate to excellent ecological condition. It also provides an opportunity to prescribe management direction for springs that are actively being managed for human uses which will support adaptation to climate change for springs ecosystems and wildlife.

Project Benefits and Next Steps

Leveraging Desert Landscape Conservation Cooperative Resources

We were able to leverage the original funding provided by the Desert LCC and BOR WaterSMART grant to secure the following additional resources:

- A two-year grant from the Doris Duke Charitable Fund's Climate Change Adaptation Fund (administered by The Wildlife Conservation Society) to rehabilitate channels and springs in areas that are experience post-fire erosion and loss of habitat.
- A multi-year collaborative project with Saguaro National Park focused on sister parks collaboration that is building on spring inventory work in the U.S. by sharing spring survey and restoration techniques with National Parks and protected areas in Mexico.
- Funding from the USFS and BLM to support spring inventory, monitoring and restoration work on their lands.

Additionally, data gathered on springs through this project was used to inform the Madrean Ecoregional Rapid Assessment conducted by the Bureau of Land Management.

Recommended Next Steps

At the conclusion of four years of work to inventory springs and conduct adaptation planning, we have identified and are actively working on a number of next steps that will enhance stewardship of springs in the Sky Island Region.

1. **Continue to train managers, researchers, and conservationists in the use of the online Springs Inventory Database in an effort to expand use of the database.** Continuing to train land and resource managers and other interested spring stewards in use of the database will engage them in use of the database and improve our landscape-level information base on the status of springs.
2. **Incorporate spring inventory and assessment data into large landscape planning efforts** including Landscape Conservation Design being conducted by the Desert LCC, and programmatic NEPA efforts being conducted by the Coronado National forest and other federal land management agencies in the Desert LCC geography.
3. **Engage managers and practitioners in use of the Arizona Springs Restoration Handbook for spring restoration projects and revise as needed.** Over the coming year we will be working to reach out to managers and practitioners in the Desert LCC geography to make them aware of the newly released restoration guidebook and to identify projects within the Sky Island Region where we can collaboratively utilize the handbook. We anticipate using this first version as a working version and releasing a second version based on feedback and review in 2017. We are already working to expand the section related to choice of plants at restoration sites, as well as to develop more explicit information on how to incorporate climate change considerations.
4. **Expand the Adopt-a-Spring program to include more priority sites in the Sky Island Region, and revise protocols as needed based on findings and practitioner/manager input.** Seasonal monitoring of springs will be an increasingly important aspect of understanding and tracking changes in springs ecosystems. It is necessary to document the full suite of flora and fauna supported by a spring, to detect seasonal fluctuations in flow, and to detect long-term changes in flow volume. The program has gone well in its first two years and we recommend expanding the number of sites on the monitoring roster. We recommend working with project partners to identify sites they are planning to conduct restoration or other management activities at in the coming years so that Adopt-a-Spring monitoring can be initiated ahead of management actions. We recommend adding more monitoring sites and eventually rotating sites out of monitoring for a "rest period" of at least a year. This will reduce long-term impacts to spring sites from monitoring activities, as well as providing volunteers with a more diverse roster of sites to monitor, hopefully helping to maintain interest in the program.
5. **Further catalogue and analyze how fire is influencing springs in the Sky Islands, as well as how springs may be influencing fire behavior on the landscape.** Based on our initial findings, springs are experiencing a diversity of negative influences from fire in Sky Islands, particularly post-fire erosion. Some of these impacts may be addressed through post-fire restoration efforts, both at spring sites and upslope. Our initial results also indicate that springs may be important

refugia for the regeneration of species following fires. Further information in support of this idea, and development of management responses that take advantage of this information may be essential for springs and ecosystems in the face of changing fire regime across the west.

6. **Collect new springs inventory information in different hydrogeologic areas of the Sky Island Region, particularly northern Mexico,** and compare parameters and characteristics across different areas to better understand the function of springs at the landscape level.
7. **Conduct a comparative analysis of spring inventory and assessment results from the Cinega Creek study area and the Upper Santa Cruz study area.** At the close of this project there is now random sample data on springs in two different hydrologic areas. This presents a new opportunity for comparative analysis between areas. Comparative analysis of areas may help us determine the utility of utilizing results from one area to make assumptions about the status of springs in neighboring, or nearby hydrologic areas.
8. **Develop a Sky Islands Wetland and Riparian Plant Identification Guide.** Throughout the assessment process, botanical knowledge was identified as a limiting factor; wetland species in arid regions are not always widely known, even amongst native plant enthusiasts. There is no specialized botanical guide for these important habitats for the Sky Island Region. This type of guide would be invaluable for use in spring inventories in the region, and would at least partially address the need for improved botanical record collection at spring inventories. It could also be a component of the Restoration Guidebook. This guide could include highlights of sensitive or particularly important wetland associated plants that surveyors should be on the lookout for, possibly by mountain range, watershed, or some smaller landscape unit to facilitate use. Use of the Southwest Environmental Information Network (SEINet; http://swbiodiversity.org/portal/index.php) and Madrean Archipelago Biodiversity Assessment MABA (http://www.madrean.org/symbflora/) online databases would allow such an effort to be constantly updated and refined so that users could compile regional or specific field guides for the area they are working in.
9. **Continue to expand inventory and restoration efforts into the Mexican portion of the Sky Island Region.** The dearth of information on springs in the U.S. portion of the Sky Island Region is clear; this lack is even more pronounced in the Mexican Sky Islands. There is not currently good spatial information on the location of springs, let alone information on their condition. It is impossible to accurately assess the condition of springs throughout the region without a matching effort in Mexico. Many of the region's most-important waterways (the San Pedro and Santa Cruz rivers, for instance) have bi-national watersheds. We are currently working with the National Park Service-led sister parks program to incorporate spring inventory protocols and database use into conservation activities at 11 collaborating National Parks and protected areas located in Arizona, Sonoran, and Baja California.
    a. **Translate spring inventory and assessment protocols, supporting training materials, the Spring Inventory Database, and relevant portions of the Arizona Springs Restoration Handbook into Spanish for use in Sonora.** We are seeking funding to work with the Springs

Stewardship Institute to translate spring inventory and assessment protocols into Spanish, offer inventory and assessment trainings in Spanish to springs stewards in Sonora, and translate the Springs Inventory Database into Spanish.

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