DEVELOPING A GEODATABASE AND GEOCOLLABORATIVE TOOLS TO SUPPORT SPRINGS AND SPRINGS-DEPENDENT SPECIES MANAGEMENT FOR THE DESERT LANDSCAPE CONSERVATION COOPERATIVE: OCTOBER 30, 2015 FINAL REPORT (AGREEMENT NUMBER R13AP80031)

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INTRODUCTION

Springs are among the most biologically diverse and culturally important ecosystems on Earth, supporting an estimated 20 percent of the nation's endangered species, and a vast, poorly known array of rare species and cultural resources (Springer et al. 2014). Many endangered species, and numerous rare or endemic species of plants, invertebrates, amphibians, and fish are found only at springs in North America. Most Native Americans on the Colorado Plateau consider springs to be sacred landscape features. They use the water of specific springs for ceremonies, to gather ethnoecological resources, and to train their youth in cultural values. Springs also are important as historical sites, and to federal, state, and local resource managers as water sources for administrative operations, cities and towns, wildfire control, critical aquatic habitat, and recreation. Springs provide the base flow of many western rivers: we estimate that springs provide 20 percent of the base flow of the Colorado River. Many ranches and farms use springs for potable water supplies, and most hatcheries in the West use springs water for raising fisheries stock. Bottled water is often derived from springs, and sales in the U.S. exceed $5 billion/year. Yet despite their importance as natural and economic resources, springs are incompletely mapped, poorly studied, inadequately protected, and often are overlooked by managers as focal points of bio-cultural diversity and ecological and economic sustainability.

Springs are common, with more than 35,000 named springs in the nation, but with at least more than an order of magnitude more U.S. springs unnamed and many unmapped. Given their importance, documentation of the distribution of these ecosystems merits further attention; however, prior to the efforts of the Springs Stewardship Institute (SSI) no large landscapes in the Southwest. perhaps excepting some Tribal and military reservations, have had accurate springs mapping, including seven National Forests in Arizona, Nevada, Utah, and Colorado, the larger of the 24 National Parks of the Colorado Plateau, the many Bureau of Land Management (BLM) units. Improving stewardship requires understanding springs distribution, condition, uses, and threats. The conspicuous lack of basic springs mapping and other data render management of these irreplaceable resources erratic and incomplete.

Understanding of springs ecology is limited. Although much energy and funding has been devoted to studying and protecting wetlands, streams, and aquifers, little is known about a critical link between these resources—where water from aquifers reaches the surface to form streams and wetlands. However, recent efforts to restore springs have demonstrated that as long as groundwater supplies are not jeopardized, springs ecosystems are remarkably resilient, and springs habitats can readily be rehabilitated. Land managers have begun to recognize the need for accurate, accessible information on springs distribution, ecological integrity, the rare species they support, and the risks to these resources presented by climate change and other ecological stressors. SSI has identified specific biological and physical research questions designed to meet these information needs, and developed a Springs Inventory Protocol (SIP) to encourage the use of a standardized methodology. We describe methods to efficiently survey and assess the biological and physical characteristics of springs ecosystems. Comprehensive inventory requires data collection in interdisciplinary categories that are intricately related—geography, geomorphology, geology, soils, flora, fauna, water quality, flow, and images. SSI also developed a springs ecosystem assessment protocol (SEAP) to evaluate the condition/value and risk of springs' natural and cultural resources to anthropogenic impacts in relation to the administrative context. SSI tested and refined these protocols for more than a decade by surveying springs in the desert Southwest. We also developed a relational database that allows us to analyze a broad array of springs-related topics and research questions that can be integrated into other database or GIS systems. Access to this information enables resource management agencies, researchers, NGOs, and Tribes to better understand and protect springs and the species that they support.

Resource managers concerned with conservation of natural and cultural resources are faced with many challenges, including water scarcity, land-use conversion, impacts to traditional or historical resources, sensitive species protection and recovery, invasive species, and a range of other complex issues—all of which are amplified by climate change. In response, the Bureau of Reclamation (Reclamation) is participating in the Desert Landscape Conservation Cooperative (DLCC). This effort represents a broader vision of conservation that includes working with partners across landscapes to ensure that science capacity is in place to enable resource managers to successfully address these 21st century conservation challenges.

PROJECT GOAL AND OBJECTIVES

The goal of this project was to provide land managers with comprehensive, current information regarding the distribution of springs and springs-dependent species across the US areas of the Desert LCC in a secure, accessible, and user-friendly format that allows for analysis of springs ecosystem vulnerability to land management practices and climate change.

The objectives of the DLCC effort were to invite states, Tribes, irrigation districts, water districts, universities, nonprofit research institutions, nonprofit organizations, and other entities with water or power delivery authority to leverage non-federal monies and resources by cost sharing with the Bureau of Reclamation on applied science projects, to meet shared priorities with Desert LCC (DLCC) partners that are designed to enhance the management of natural and cultural resources in a changing climate. This includes analyzing the impacts of climate change and other landscape scale stressors on natural or cultural resources that affect or are affected by water resources management, and developing tools to assess and adapt to those effects within the boundaries of the Desert LCC. Such projects focus on the shared priorities of Reclamation and LCC partners identified through the formation of the Desert LCC. Projects also support ongoing efforts under the SECURE Water Act, and the Fish and Wildlife Coordination Act (FWCA).

RESULTS BY TASK

OVERVIEW

The methods and results of four objectives of this project are listed and described below, and are summarized in Table 1.

Table 1: Summary project progress by task and schedule. Abbreviations: EAC – Eastern Arizona College, PC – Prescott College, SDS – springs dependent species

Tasks and Milestones (shaded)	Start	Finish	Status
1.1 Compile publicly available data	10/1/13	11/18/13	Completed
1.2 Engage land managers	10/1/13	10/30/13	Completed
1.3 Refine online inventory database	10/1/13	10/17/13	Completed
2.1 Identify information sources	10/1/13	11/29/13	Completed
3.5a Begin training EAC students	10/7/13	10/31/13	Completed
1.4 Secure and publish geodatabase	11/20/13	11/28/13	Completed
1.5 Import additional springs data	11/28/13	8/3/15	Completed
1.6 Publish WFS applications	12/2/13	5/15/14	Completed
3.1 Develop outreach program	12/2/13	7/2/14	Completed
3.2 Webinars/online support	12/1/14	8/3/15	Completed
Geodatabase & WMS published	12/20/13	12/20/13	Completed
Webinar 1	1/8/14	1/8/14	Completed
3.4 Develop training videos, tutorials	1/9/14	2/15/15	Completed
Webinar 2	4/23/14	4/23/14	Completed
3.5b Prescott College course	5/19/14	6/13/14	Completed
PC course complete	6/13/14	6/13/14	Completed
3 mapping apps published	5/15/14	5/15/14	Completed
2.2 Compile SDS Information	6/2/14	1/15/15	Completed
Webinar 3	7/30/14	6/26/14	Completed
EAC surveys complete, data compiled	7/1/14	12/31/15	Completed
2.3 Reporting and Mapping	7/22/14	1/15/15	Completed
SDS data published	8/27/14	1/15/15	Completed
3.3 Workshop Las Vegas October 2014	10/15/14	10/16/14	Completed
Webinar 4	12/1/14	8/15/14	Completed
Webinar 5	1/15/15	12/8/14	Completed
4.1 Begin analysis of springs use data	2/2/15	3/27/15	Completed
Webinar 6	3/4/15	3/17/15	Completed
Webinar 7	6/3/15	3/26/15	Completed
4.2 Develop climate change risk model	4/1/15	6/9/15	Completed
EAC Data Entry Completion	6/19/15	6/19/15	Completed
4.3 Test and apply climate change model	6/19/15	9/1/15	Completed
3.6 Reporting	7/1/15	9/15/15	Completed
Draft final report submitted	8/24/15	9/24/15	Completed
Climate change model published as WMS	9/1/15	8/25/15	Completed
Webinar 8	9/2/15	10/28/15	Completed
Draft Final report submitted	9/30/15	9/30/15	Completed
Final report submitted	10/30/15	10/30/15	Completed

Objective 1 – Develop a springs geodatabase, and provide a secure, accessible Web Mapping Service (WMS) map of springs throughout the Desert LCC, combined with simple geocollaborative tools that will allow cooperating agencies, Tribes, institutions, NGOs and researchers to easily access and, if they wish, share information across administrative boundaries, and to engage volunteers to locate unmapped springs and assist with monitoring efforts.

Building on SSI's previous and current work in Arizona: The largest barrier to improving our understanding and stewardship of springs remains the lack of high quality, accessible data. Over the past six years, SSI staff have compiled the most comprehensive geodatabase of Arizona springs available. We combined several major datasets (Arizona State Land Office, NHD, GNIS, and Arizona Department of Water Resources, many data of which were assembled from the U.S. Geological Survey). Focusing on one land unit at a time, we resolved duplicates where locations and names were different and conducted field inventory and assessments for more than 1000 springs. With DLCC funding, we expanded this effort to include the entire DLCC landscape.

Stage 1 - Compile publicly available data into a secure platform: We collected publicly available data on springs distribution within the DLCC boundary from many sources in addition to those listed above, including the cartographic feature files (CFF), county and state data, land management agencies, published reports, and individual researchers. We also scanned DRGs to locate additional springs for much of the DLCC.

We compiled georeferenced data for 15,520 springs among the five DLCC states into one feature class, with documentation of the information sources. We included a domain field that indicates sensitivity of information as directed by the land manager (e.g., presence of sensitive species or cultural resources), and a Boolean field denotes whether the location is already publicly known (published on maps or in reports, or in the NHD or GNIS databases). We imported the spring name, when known, but many springs were simply listed as unnamed. We populated additional fields, including the county, land unit, elevation, 8-digit HUC, Quad name, distance to the nearest spring in meters, and LCC. The feature class also contains the inventory status and a hyperlink field that points to any available reports. An ID field was used to link the geodatabase to non-spatial data in the online database (see Stage 3 below). Editor tracking is enabled, and the geodatabase is hosted on a domain at http://springsdata.org/index.php. The geodatabase also includes feature datasets that include reference layers for individual land units. These typically include boundaries, roads, streams, and wilderness areas.

We developed metadata and data quality controls according to best practice standards. We stored spatial data in an Arc SDE geodatabase on our MNA server that is dedicated to springs information management at https://arcgis.springsdata.org/arcgis/admin/login. All data on the server are backed up hourly, and incremental backups are saved off-site. Having completed the initial data compilation (Figure 1), we continue to add springs locations as additional datasets become available. As we increase collaboration with agencies, NGOs, and independent researchers, we are adding new springs every week.

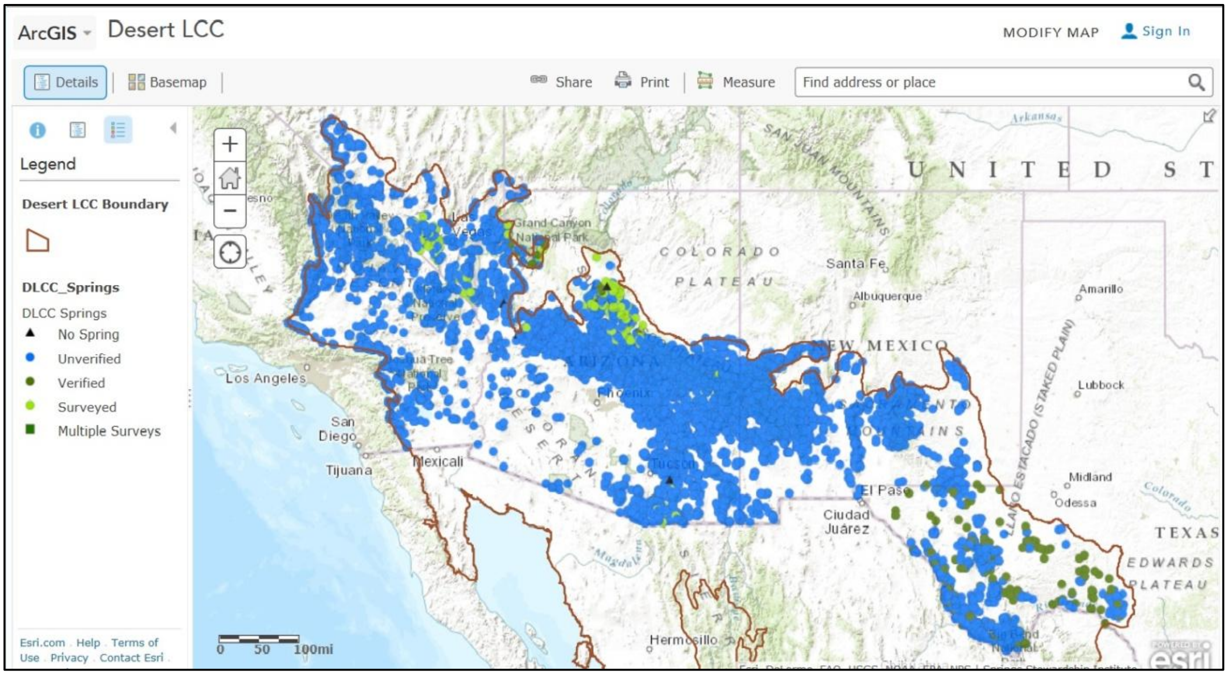

Figure 1 Online interactive map of publicly available springs distribution data within the DLCC.

We published distribution data as a web mapping service (WMS). An interactive map is available at [***http://arcg.is/1J3denI***](http://arcg.is/1J3denI) (Figure 1). These publicly-available maps do not include springs that have been identified by the springs stewards as sensitive sites; nor do they include locations that are not already publicly available. All springs data have been migrated to the Online Database (Stage 3).

Stage 2 - Engage DLCC land manager collaboration: We collaborated with many partners to build a community for springs research in the Desert Landscape Conservation Cooperative. Partner participation takes many forms, including sharing of non-sensitive data and providing technical support. Many volunteers helped us to refine our protocols and methods by participating on survey trips – individuals, students, agency representatives, universities, and Tribes. We deeply appreciate their support and assistance. We have finalized a national level MOU with the US Forest Service that designates SSI to host all of their data.

Outreach Database

We regularly updated our outreach database that now contains contact information for 392 federal, state, Tribal, and NGO resource management offices within the DLCC, and 486 contacts associated with those offices.

Listserve

Our DLCC Springs listserve currently contains 461 members, with whom we communicate at least monthly through webinars, telephone calls, meetings, and workshops to share and contribute information on the status of springs under their jurisdiction. We developed agreements with participating springs managers about: 1) where and how springs data are to be stored, 2) who has access to which data, and 3) what levels of permissions apply to some or all of the information. Where possible, we have enabled springs stewards to officiate over permissions, giving them jurisdiction over information sharing. In cases where technical guidance is needed for enabling data access permissions, we work with the stewards to ensure security and appropriate permission granting.

Website Enhancements

We redesigned our SSI website at http://springstewardshipinstitute.org. This website provides the technical framework to continue to build a community to support springs research through interactive geospatial tools, information about springs ecosystems and stewardship, survey protocols, the online database tutorial, links to other research efforts and publications, latest news about upcoming workshops and training, and information about opportunities to form additional collaborative partnerships. We update this website regularly, and have added several new sections, pages, and links.

Table 2: DLCC presentations, meetings, and coordination activities conducted by Jeri Ledbetter (JDL) and/or L.E. Stevens (LES), not including the webinars listed in Table 1.

Colorado River Guides, Colorado River in Grand Canyon (Both) - 4/1-6/2014
Eastern Arizona College students and the BLM training (LES) - 4/24-25/2014
Mohave Network of the National Parks (JDL) - 5/7/2014
Flagstaff workshop (LES) - 5/6-7/2014
Hualapai Tribe, consultation - 5/12/2014
Aquatic Sciences Meeting in Portland, OR (LES) - 5/20/2014
Sky Islands Alliance training, Tucson (LES) - 6/16-17/2014
Riparian Symposium, Flagstaff (Both) - 6/18/2014
Society for Conservation GIS in Monterey (JDL) - 7/12-15/2014
North Kaibab Paiute, Hopi Tribe, Kaibab National Forest training (LES) - July 28-29, 2014
Poster for DLCC meeting in San Francisco - 9/2014
Webinar for White Mountain Apache Tribe (Both) - 10/2/2014
Private webinar requested by Genevieve Johnson (Both) - 10/7/2014
Workshop for White Mountain Apache Tribe (Both) -10/22-23/2014
Meeting with Arizona Game and Fish, Trout Unlimited (Both) - 11/1/2014
Meeting with City of Flagstaff planners re: restoration of Old Town Spring (LES) - 11/8/2014
Meeting with Southern Colorado Parks Network - (Both) 11/9/2014
Meeting with NPS hydrologists re: GRCA springs mapping (Both) 11/14/2014
Meeting with USGS (D. Sarr) re: development of riparian ecosystem model (LES) 11/18/14
Meeting with MNA Directorship re: SSI progress on DLCC project
Meeting with K. Sparks re MS thesis prep on springs riparian vegetation (LES) 11/18/2014
Confer with K. Karlstrom and L. Crossey re: springs geochemistry (LES) 11/23/2014
On-site with Ft. Collins Entomology Collections for invertebrate specimens (LES) 11/24-26/2014
1/2 day springs ecology/restoration class for NAU at Montezuma Well (LES) 12/2/2014
Coordination about springs use with resource managers (LES) 12/2-5/2014
Prepared manuscript on Pakoon Springs restoration (LES) 12/3/2014
Interview Rich Rudow re: lower GRCA springs (Both) 12/4/2014

Webinar, introduction to the database for Pima County (JDL) - 12/8/2014
Don Sada, Desert Research Institute, Reno (both) 12/6-11/2014, with LES seminar on springs to DRI on 12/9/2014
Springs Online coordination meeting (Both) 12/15/2014
Met with USGS re: aquatic inverts collection, curation (LES) 12/4/2014
AZ springs restoration handbook preparation (LES) 1/5-9/2015
Coordinate DLCC SDS plants with T. VanDevender (LES) 1/9/2015
Met with A. Springer and K. Junglans re: DEVA springs project (LES) 1/12/2015
DLCC springs and climate change meeting with J. Jenness (LES) 1/14/2015
Springs mapping project with Gregg Janeish, Adventure Science, (LES) 1/15/2015
Coordinate springs mapping and database with White Mountain Apache Tribe (Both) 1/22/2015
Rumble on the Mountain presentation at the Orpheum, Flagstaff (LES) 1/24/2015
Slide Fire, Mega-wildfires, and Springs presentation at MNA (LES) 1/22/2015
Springs and pollinators discussions at the USDA Bee Lab (LES) 1/25-31/2015
Grand Canyon Trail Hiking Guides presentation on SDS at South Rim (LES) 2/8/2015
AZ springs restoration handbook preparation (LES) 2/9-13/2015
Review of springs ecosystem issues with J. Schmidt (phone call) (LES) 2/13/2015
Coordinate springs microclimate meteorology with D. Stanitski (LES) 2/14/2015
Meet with K. Sparks, coordinate MS thesis ms prep springs vegetation (LES) 2/15/2015
SDS expert taxonomists call (Both) 2/17/2015
SDS taxonomists call with D. Sada (Both) 2/18, 20/2015
ASU SDS (LES) 2/24/2015
Prescott College public lecture on springs and SDS (LES) 2/27-28/2015
Meeting with City of Clarkdale re: restoration of Clarkdale Big Springs (LES0 3/2/2015
Coordinate on BLM springs with J. Cockman (LES) 3/6/2015
AZ springs restoration handbook preparation (LES) 3/9-13/2015
Riparian vegetation model meeting with D. Sarr; call with S. Spangle FWS (LES) 3/10/2015
Coordinate with Big Bend National Park on use of the database (LES) 3/10-28/2015
Coordinate on BLM springs with J. Cockman (LES) 3/13/2015
Webinar for FWS re: DLCC project with S. Spangle, PHX Field Office (Both) 3/17/2015
Worked with E.G. North on land Mollusca ms at DLCC springs (LES) 3/23-29/2015
Grand Canyon River Guides Training Seminar (Both) - 3/29/2015
Participated on Rio Grande river trip with Big Bend NP staff (Both) - 4/23-4/29/15
BLM springs inventories with J. Cockman in Safford District (Both) 6/13-17/2015
Held two-day Springs Inventory workshop with 14 participants (all staff) - 5/20-5/21/15
Conducted 1-day workshop for Friends of Nevada Wilderness (LES) - 6/18/2015
Organized online training for Friends of Nevada Wilderness (JDL) - 6/21/15
Map Gallery - Grand Canyon springs at ESRI User Conference in San Diego (Jeri) - 6/21/15
Presentation of Online Geocollaborative Tools at ESRI User Conference (Jeri) - 6/23/15
Inventoried Apache-Sitgreaves springs (BOTH) 6/29 - 7/13/2015
Communicated with E.C. Granfeld regarding rare AZ SDS *Salix* 7/10, 8/15, 9/28/2015
Attended Desert LCC meeting in Tucson (Both, with Jeff Jenness) with a demonstration of online database (Jeri) - 8/4-8/6/15
Coordinated SSI volunteer K. Slutz on presentation to DLCC Oct 15, 2015 (LES)
Finalized National level MOU with the US Forest Service designating SSI as the lead in compiling and hosting springs data - (Both) - 9/30/15

Figure 2 Site information page of the Springs Online database with the General information tab displayed.

Stage 3- Refine "Springs Online" Springs Inventory Database: Since we launched our Springs Inventory Database online in the spring of 2014 at springsdata.org, we added much new functionality (Figure 2). We had a strong positive response from many land managers, researchers, Tribes, and agencies across the DLCC. Currently we have 261 database users, several of whom include prominent land management agencies and southwestern springs researchers and taxonomists. The database contains information on 13,675 springs and 4,207 surveys, with more than 1,000 Level 2 comprehensive baseline surveys.

New functionality on the site form includes the source of information, and whether or not the site is publicly known. This allows land managers to designate which data are not available to the public without permission. We also included sensitivity status, allowing land managers to designate whether a site's location is sensitive, survey data are sensitive, both as sensitive, or neither are sensitive. This structure was requested by several land managers during and after

DLCC webinars. We also added fields for the LCC, USGS quad, and HUC. We updated all reported springs in the DLCC with this information.

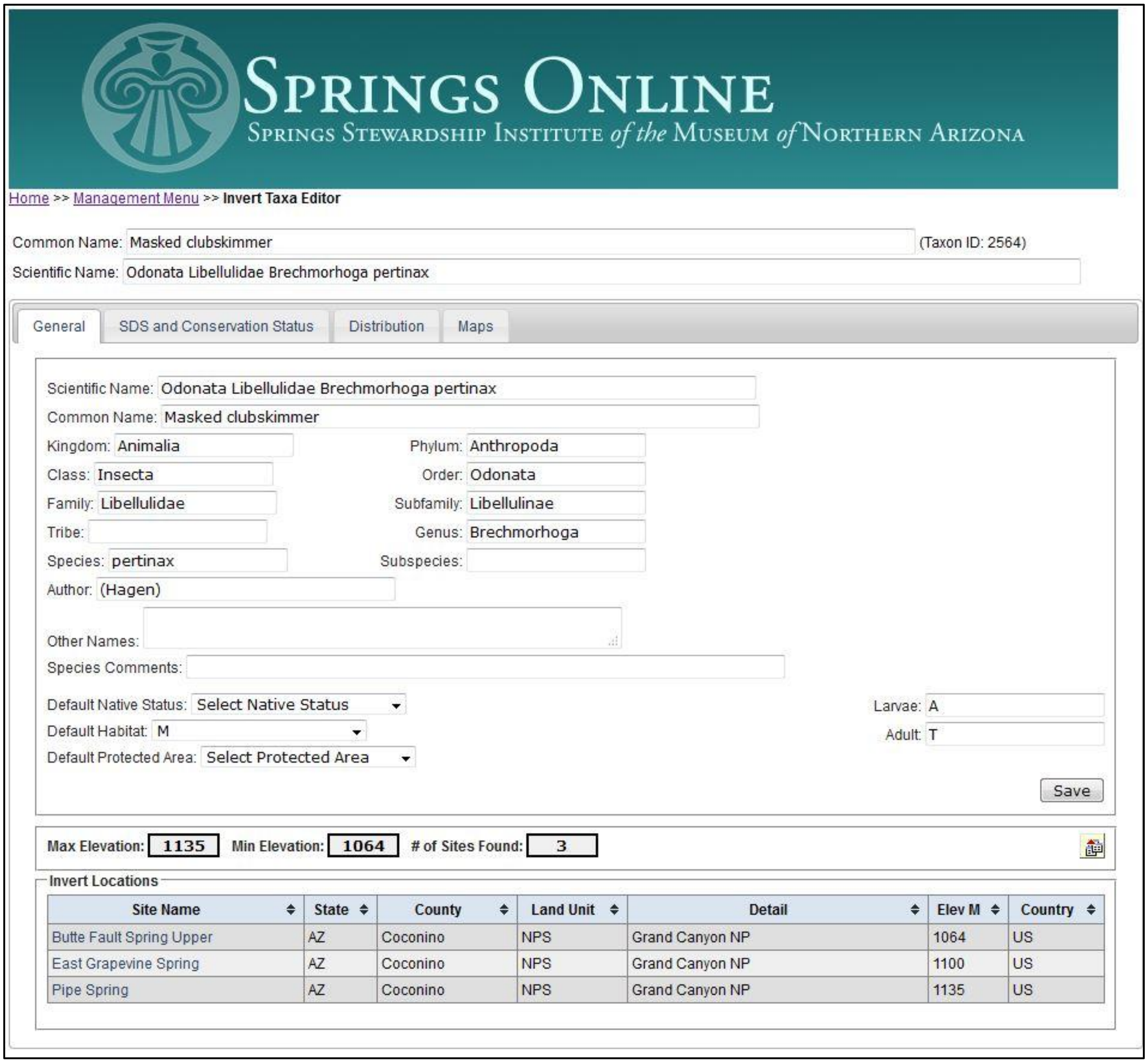

Figure 3 Springs Online interface at springsdata.org viewing information about Brechmorhoga pertinax, an endemic springs-dependent dragonfly in Grand Canyon National Park, Arizona.

We enhanced the flora and fauna sections of the database to include springs-dependent species (SDS) information, including federal listing, and NatureServe and global conservation status, as well as springs-related life history, level of endemism, and pertinent references (Fig. 3). We also added the ability to view site elevation range of reported species, an occurrence map using Google maps or Google Earth, uploadable range maps, or downloadable occurrence data as a *.csv file.

We designed the permissions structure after lengthy discussions among SSI, and managers, NGOs, and other researchers. Data security is a primary concern for many springs stewards, particularly Tribes and the National Park Service. Many land managers regard cultural significant and rare or sensitive SDS as of primary importance in springs management decisions. The Springs Online database now enables us to house and securely protect sensitive information, often which is viewed as intellectual property of the springs steward, and which they do not wish to share with others without specific permission. Of particular concern to some managers have been springs associated with caves or archaeological sites, and locations of springs that are not currently mapped. We worked closely with several Tribes to compile and archive sensitive data on reservation springs, and those collaborations greatly advanced Tribal efforts to acquire further springs stewardship funding. We also worked closely with the National Park Service to document and archive data on springs in lower Grand Canyon, where the Tribal boundary is in dispute. The elements of database population and data security often required detailed discussion with the collaborators to identify, obtain, compile, protect, archive, and report on their data. Also, we added the ability for land managers to grant or remove access privileges for other users, thereby removing SSI from having full responsibility for such changes.

Stage 4– Secure and publish the geodatabase: Our ArcSDE geodatabase is housed on our dedicated server. Using ArcGIS users, roles, and permissions, we provide controlled access to published Web Feature Services (WFS) for specific land units, while maintaining security for sensitive information. Unlike the WFS, these services are editable. Currently we have set permissions for our collaborators at Sky Island Alliance, Northern Arizona University, Grand Canyon National Park, several Tribes, and other land managers to allow them to enter and edit springs data.

Stage 5– Compile additional springs data: We imported additional contributed springs location data into the geodatabase, and we scanned digital raster graphic (DRG) maps to locate additional springs. We imported or manually entered springs survey data contributed by collaborators into the Springs Online database. These include: 1) Forest Service data from the Spring Mountains National Recreation Area that were collected using USFS protocols for inventorying groundwater dependent ecosystems (USDA Forest Service 2012); 2) springs data from the Grand Canyon Ecoregion, collected and contributed by Grand Canyon Wildlands Council, Grand Canyon Trust, the National Park Service, and independent researchers; 3) data collected by the Sky Island Alliance and BLM in southeastern Arizona; 4) data collected for National Forest Service planning in northern Arizona; and 5) publicly available water chemistry and flow information, as well as other datasets from the BLM, independent researchers, the US Geological Survey, and other sources. Of the 13,675 springs that we documented in the US portion of the DLCC, 2,222 are springs have data that are not available to the public.

In addition to inventory data, we compiled springs ecosystem assessment data for many the above landscapes, as well as new data collected by students and staff in participating land management units. We use these data to provide managers with estimates of springs ecological integrity and vulnerability to anthropogenic and climate related risks.

Stage 6– Publish Web Feature Service (WFS) applications: We published existing data to an interactive DLCC landscape map (http://arcg.is/1J3denI) that we presented to project participants through webinars, meetings, and on our website. We maintain maps and applications for individual land units and areas, such as Sky Island Alliance (Fig. 4), Spring Mountains NRA (http://bit.ly/13xyOtL), Nevada BLM (http://bit.ly/1jfrt8u), Coconino County, and the City of Flagstaff (http://arcg.is/1IyMp7m). We created non-public mapping services for Grand Canyon National Park, Kaibab National Forest, Coconino National Forest, Apache-Sitgreaves National Forest, the White Mountain Apache Tribe, and other land units in the DLCC. This allowed us to engage collaborators to assist in quality control, removing duplicate springs and adding unmapped locations. Collaborators can open the services in ArcGIS and combine

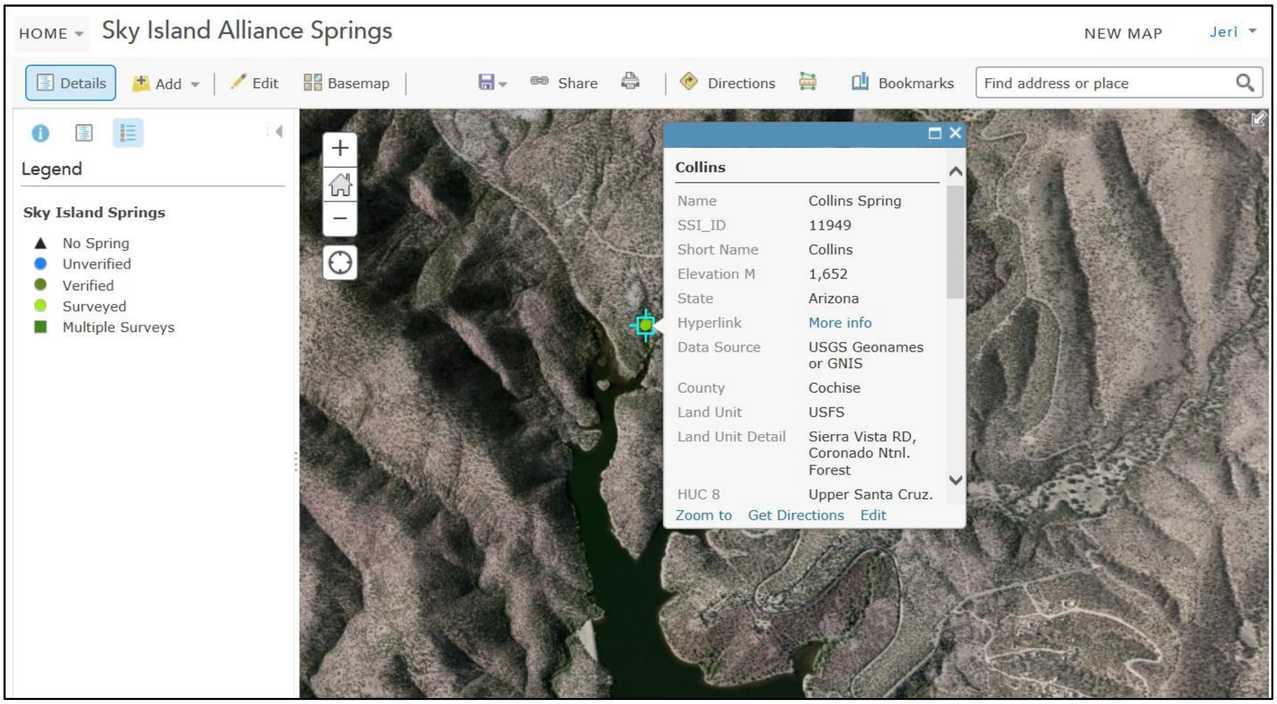

Figure 4 Web Mapping Service developed for the Sky Island Alliance.

them with their own layers. We also developed online applications that do not require GIS expertise to access. These geocollaborative mapping applications provided additional capability to partners for adding, editing, and querying data. We developed these applications iteratively, based on feedback through webinars and online sessions. We continue to manage and enhance these products as crowd-sourcing and collaborative tools to further engage the management community and the public in monitoring efforts.

Objective 2 - Develop a list of and map macroscopic springs-dependent species (SDS) and associated information throughout the DLCC.

Springs types and associated microhabitats were defined on the basis of their sphere of discharge by Springer and Stevens (2008), who described 12 active springs types and 13 geomorphologically-defined springs microhabitats. Many microhabitats with associated biological assemblages co-occur within some individual springs, greatly contributing to biodiversity and species packing (Hallam 2010). We defined springs-dependent species (SDS) as those that require, or most often occur in, springs or springs-supported habitats during one or more phases of their life cycles. Some springs types support endemic (unique) taxa or other SDS, particularly limnocrene (pool-forming), mound-forming, helocrene (marsh-forming), and gushet springs (e.g., Spamer and Bogan 1994, Stevens and Meretsky 2008, Stevens and Polhemus 2008, Stevens and Bailowitz 2009). For example, several endemic subspecies of speckled dace (*Rhinichthys osculus*) and many pupfish (*Cyprinodon* spp.) are SDS, occurring in hillslope or limnocrene springs run-out channels, which are springs-supported habitats (Minckley 1973; Minckley and Unmack 2008). Rheocrene (in-channel) springs are somewhat less likely to support endemic or rare SDS due to increased flooding disturbance and reduced genetic isolation. In addition to springs type, several other factors influence species richness and the occurrence of SDS at springs, including: springs habitat area, isolation, and geomorphic complexity (Hallam 2010, Schaller 2013).

SDS include a wide array of aquatic aquatic and wetland biota [e.g., Hydrobiidae – most *Pyrgulopsis* springsnails; many elmid riffle beetles; many stoneflies (Plecoptera); some freshwater amphipods and isopods (e.g., Socorro isopod - *Thermosphaeroma thermophilum*); and many cyprinodontid pupfish],*Nebria* carrabid ground beetles, as well as wetland plant species (e.g., Orchidaceae – *Epipactis gigantea* heleborine orchid; Cyperaceae – *Carex specuicola* Navajo sedge; Asteraceae – *Flaveria mcdougalii* McDougal's flaveria; Primulaceae – *Primula specuicola* cave-dwelling primrose). More than 120 species of *Pyrgulopsis* springsnails are known from western North America, the majority of which occur at the sources of individual springs, and among which at least 17 are or have been considered for listing as endangered species. During this project, LES collaborated with Robert Hershler of the Smithsonian Institution to name a new DLCC springsnail species, the Hualapai springsnail (*Pyrgulopsis hualapaiensis*; Hershler et al., submitted). Leopard frogs (Ranidae: *Lithobates* spp.) in the Southwest are commonly found at springfed ciénegas, fens, and other helocrene and low gradient hillslope springs (Clarkson and Rorabaugh 1989). Numerous native fish species in the DLCC are SDS (Beckman 1952, Minckley 1973, Sublette et al. 1990, Sigler and Sigler 1996, Wallace and Zaroban 2013). We exclude as SDS those generalist species that occasionally (non-obligatorily) occur in springs-generated habitats, including non-native crayfish and non-native fish. However, some generalist taxa occur obligatorily in springs in particular regions and such populations are regarded as being conditionally SDS. For example: American Dipper (*Cinclus mexicanus*) nest virtually obligatorily in cool spring-supported streams when they nest at low elevations in the arid Southwest (Stevens et al. 1997); and northern water shews (*Sorex palustris*) may occur primarily along high elevation springfed streams and in wet meadows (Hoffmeister 1986).

Endemic, rare, or endangered SDS are often important considerations for resource management. However, a regional synthesis of macroscopic SDS has not previously been compiled. SSI developed a georeferenced list and interactive online maps of springs-dependent sensitive plant and animal species throughout the DLCC. We compiled data from NatureServe, which includes all state-identified Natural Heritage lists of sensitive species. In addition, we reviewed existing literature and museum collections to compile previously unsynthesized specimen information. We interviewed many university, museum, and collections experts, curators, and retired or private individuals who were knowledgeable about SDS plant, invertebrate, and vertebrate species distributions in the DLCC.

Stage 1 - Identify information sources: NatureServe, an international network of natural heritage programs and conservation data centers, lists the DLCC state and national lists of sensitive plant, invertebrate, and vertebrate species data. We requested and received a dataset from NatureServe on the status of all aquatic, wetland, and riparian species in the DLCC. We checked the habitat use and affinity of those species. Although springs are not specifically indicated as a habitat type for many entries in NatureServe, we researched springs habitat use by taxa known to be tightly restricted to springs, and evaluated habitat requirements of many taxa considered to be likely SDS.

We further refined our understanding of springs dependence through interviews with recognized experts in botany, invertebrate taxonomy, ichthyology, and herpetology at regional and national universities, museums, and private collections. We interviewed staff at the following institutions: Richard Bailowtiz (Private Researcher – desert Odonata); Arizona Game and Fish Department (David Rogowski and Jeff Sorensen); Brigham Young University (Shawn Clark); Coconino National Forest (Heather Green), Colorado State University (Boris Kondratieff – Plecoptera); Desert Research Institute in Reno NV (Donald Sada, springs invertebrates and fish); Harvard University (Philip Perkins – hydraenid beetles; G. Alpert – ants); the National Museum of Natural History (Oliver S. Flint Jr. – aquatic entomology; Donald Harvey – Pyralid moths; Robert Hershler – Hydrobiidae springsnails; Norman Wooley – Stratiomyidae flies); Northern Arizona University (Glenn Rink – Botany); Sky Island Alliance in Tucson (Tom VanDevender); Texas A&M University (Dean Hendrickson – springs fishes);University of Arizona (Carl Olson – general entomology); the University of California at Berkeley (Cheryl Barr, William Shepard-dyropoid beetles); University of Kansas (Andrew Short – hydrophilid beetles); University of New Mexico (Geoff Carpenter - herpetofauna); USDA Logan Bee Research Lab (Terry Griswold - bees); and other taxonomic experts.

Stage 2 - Compile and quality control SDS information: We compiled the above information on aquatic, wetland, and riparian flora and fauna in the DLCC region, and reviewed the species to evaluate their status as SDS. The initial SDS list included nearly 4,000 macroscopic species of plants, invertebrates, fish, amphibians, birds, and mammals. We engaged taxonomic experts to review data on: 1) which plant, invertebrate, and vertebrate taxa were springs-dependent, 2) what references document those SDS habitat affinity and distribution designations, and 3) which institutions housed relevant collections of those species. We also queried experts for data about groups that are poorly known taxonomically and that require further study (e.g., Physidae aquatic snails, Turbellaria flatworms, etc.).

While NatureServe provides conservation information on a vast array of species, our discussions with experts about SDS revealed many, hitherto poorly or undocumented species that require springs for some or all of their life histories. SDS recognized by federal or state governments as worthy of management attention as rare, threatened, or endangered were specifically noted.

This SDS information has been imported into the Springs Online database. We list 860 plant species, of which 568 are regional to highly localized endemics, and 5 have been or are considered for federal listing; 701 invertebrate species, of which nearly 450 appear to be regionally to locally endemic SDS, particularly including the hydrobiid springsnails and dryopoid aquatic beetles; and 140 vertebrate species, with 56 species considered for, or presently federally listed and many of which are locally endemic. Thus, we list more than 1,700 SDS in the Southwest, likely a far larger proportion of species than previously recognized by most scientists and stewards. The SSI dataset also includes taxonomy, ESA and NatureServe national and state conservation status, the springs or overall range in which the SDS occurs, as well as (where known) springs microhabitat associations, range maps, as well as references to information sources. This list continues to be refined as we and interested experts continue to discover and clarify the extent of springs dependence among these and additional as-yet-unrecognized taxa.

Stage 3 - ***Reporting and mapping:*** Having recorded the individual springs at which SDS are known to occur, SSI published range maps for many species at Springs Online, where users with appropriate permissions can view the information. We also imported 43,506 records of specimens from Dr. Stevens' invertebrates database that were collected at springs. From Springs Online, users can download occurrence data into*. csv files, view them in Google Maps, or download them to We also developed a mapping application that allows springs stewards to view, analyze, and download HUC-based SDS data, available at *http://arcg.is/1O31IKi*. We also developed a narrative mapping application that allows springs stewards to easily identify species of concern within their area. This application is available at http://springs.maps.arcgis.com/apps/webappviewer/index.html?id=15b696f26b2f446fb9295e699c79c84b.

We continue to compile background literature on DLCC SDS into a bibliography that is available at Springs Online. Whereas many stewards have sensitive intellectual information associated with springs that are not shared, most of the SDS information is publically available in the scientific and agency management data. We have not yet attempted to georeference all localities at which individual SDS have been detected, as that effort is far beyond the scope of this project. Nonetheless, we will continue to improve understanding of SDS in the future, and georeference locality data as time and funding permits. Here we provide summary information on the number of SDS across the DLCC landscape, highlighting federally listed SDS.

Objective 3 – Develop an outreach program to: disseminate information about project progress; train resource managers, NGOs, students, and Tribes in data collection and interpretation and use of geocollaborative tools.

We provided support on the use of these new data and tools through in-person training sessions, quarterly webinars, a tutorial, online instructional videos, and individualized support sessions through video conferencing and screen sharing, as referenced in Tables 1 and 2 (above). Through these meetings and training sessions, SSI continues to seek feedback on the data, methodology, and tools we have developed. Communication with land managers and other interested parties is crucial to the successful use of the assembled; therefore, we used an iterative process to further refine the tools and products and conduct outreach.

Stage 1 - Develop an outreach program and volunteer base: Using contact lists developed as part of Objective 1, we invited interested federal and state agencies, Tribes, non-profit organizations, universities, museums, and independent research groups to participate in online and in-person training sessions, as well as providing them with an overview of this project. We used our now-extensive contact list, website, and partners to develop a list of collaborators and volunteers to assist with data compilation, as well as other technical activities.

Stage 2 - Quarterly webinars and online support: We conducted quarterly webinars to update participating collaborators about progress on the project (Table 1). We provide recordings some of these webinars for those who were unable to join, as well as background information for resource managers who wish to participate in the project. In addition, we provide webinars and online presentations and discussions with individual agencies, Tribes, and organizations interested in using the tools and contributing to the datasets (Tables 1, 2). We conducted a survey to request feedback from collaborators on how springs in their jurisdiction are being used, and discussed potential climate change impacts on the hydrologic basins within their jurisdiction (Objective 4). Agendas, PDFs of the presentations, and recordings of these webinars are available at http://springstewardshipinstitute.org/past-webinars. Participants have included representatives from Federal and State agencies, NGOs, academic institutions, and Tribes, as well as independent researchers.

1. Introduction to springs and SDS of the DLCC - 1/8/14
2. Springs and SDS Springs Online Database - Balancing Data Security with Access - 4/23/14
3. Springs Online database - Sharing and Contributing Data Online - 6/26/14
4. SDS of the DLCC - 8/15/15
5. Sharing and contributing data online, Pima County staff - 12/8/14
6. Sharing and contributing data online, Sky Island Alliance - 3/12/15
7. Mapping springs and SDS in Arizona - 3/17/15
8. Springs Online database - sharing and contributing data online - 3/18/15
9. Springs valuation and use - 3/26/15
10. Online access to springs and SDS data - 9/9/15
11. Final Results of the Springs and Springs-Dependent Species Project - 10/28/15

We also regularly provided individual support to collaborators through GoToMeeting screen sharing tools. When we have several similar requests, we are able to schedule an open webinar or develop a video, but for unique requests or troubleshooting, it has been more efficient to conduct short private or semi-private meetings (Tables 1, 2).

Stage 3 – Workshops: We conducted a two-day training workshop on May 6-7, 2014 in Flagstaff that was open to any of the project collaborators or others throughout the study area. We held a second DLCC workshop in Las Vegas, NV on October 15-16, hosted by the US Forest Service. These workshops provided an overview of springs ecology, inventory and assessment, risks, restoration potential, information management, and springs-dependent species. The workshops also provided specific training in SSI's inventory protocols, springs ecosystem assessment protocols (SEAP), and information management, and both workshops included visits to local springs and hands-on experience in data collection and data management. We provided instruction and hands-on opportunities on the use and utility of the tools developed in Objectives 1 and 2.

In addition to the general workshops, SSI made special efforts to conduct on-site trainings and mini-workshops for interested Tribes who are unable to attend the general workshops or needed more personalized training sessions based on individual needs as well as concerns for culturally sensitive sites. We held such a workshop for the White Mountain Apache Tribe on October 22-23 for 11 members of their staff. Since then we have provided continued data management support and online training for their staff.

We also are providing data management support for the Springs Mountains National Recreation Area and for Grand Canyon, Death Valley, and Big Bend National Parks, as well as for other interested collaborators.

Stage 4 – Develop online database tutorial and training videos: Because we recognize that demands of both time and financial resources are great for agency, Tribal, and NGO staff, we are building a set of web pages that provide detailed instructions. We published a User Manual, available at http://springstewardshipinstitute.org/database-manual-1/. As we have made many enhancements to the interface of the website, we have had to revise this user manual several times. We are continuing to develop a series of instructional online videos demonstrating the use and basic functionality of the tools we have developed. An introductory video of the database is available at http://docs.springstewardship.org/Videos/Database/SpringsOnline102015.mov. These videos provide instruction on most commonly used tasks and functionality, and are available in the database tutorial section of our website. Due to changes to the interfaces, some of these videos are obsolete, and we continue to upgrade and improve this effort under the Southern Rockies LCC project that continues until September 2016.

Stage 5 – Train and collaborate with undergraduate students: We collaborated with professors from Prescott College and Eastern Arizona College to train students to collect and compile survey data in remote landscapes where high concentrations of unmapped springs and SDS exist. These study areas span a wide range of habitat types and elevations in the Sonoran and Chihuahuan Deserts, with dramatically different topography and land management uses. Students assisted with gathering, compiling, and analyzing springs use data, to be analyzed in Objective 4.

We partnered with the Bureau of Land Management (BLM) Safford Field Office to engage students from Eastern Arizona College to inventory seeps, springs, and cienegas in several BLM Wilderness Areas in southeastern Arizona: Dos Cabezas, Peloncillos, Aravaipa, Fish Hooks, North Santa Theresa, and Redfield Canyon. The BLM/EAC team used a stratified random selection of springs throughout the target landscapes, and inventoried 29 springs ecosystems. SSI staff conducted field training with BLM Staff and students in Safford, Arizona, inventorying springs in the BLM Gila District. We hosted three online training sessions to instruct the students in data entry, and also assisted by entering data for a number of sites for them.

We conducted a Southwestern Springs Ecosystem Ecology and Stewardship class with students of Prescott College May 19-June 13, 2014. The course included class-time lectures, field trips, laboratory data entry and analysis, and report preparation, primarily at the Museum of Northern Arizona's Powell Ecology Laboratory in Flagstaff, AZ. Three multi-day field trips also were conducted at: 1) Fossil Canyon to map springs distribution (24 new springs were mapped, of an estimated 100 springs emerging there); 2) Arizona's White Mountains to inventory burned versus unburned springs; and 3) Lower Grand Canyon – a river trip to map and inventory springs. Lecture topics included springs ecosystem ecology, geohydrology, biota (botany, zoology), biogeography, water resource law and policy, use and threats, inventory, assessment, management planning, restoration and monitoring.

Stage 6 – Reporting: All SSI staff participated in development of interim, draft, and final reports covering results from each objective. These reports are available on our website, and we continue to notify participants of report availability and invited feedback at our concluding webinar. We posted this final report on our website.

Objective 4: Springs Use Assessment and Climate Change Risk Modeling

Introduction

Many aspects of biotic and water resource management in the DLCC are likely to be challenged by climate changes, which are predicted to increase ambient temperatures by 4-6°F over the next century (Alexander et al. 2011, Glick et al. 2011, Bureau of Reclamation 2012). Global circulation models (GCMs) agree as to potential impacts: increased air temperature, more erratic extreme weather, and equal or less precipitation (Knuttti and Sedláček 2012). Increased temperature and stable or reduced precipitation mean that the proportion of incoming moisture lost to evapotranspiration (ET) will increase. ET removes all but a few percent of the total incoming precipitation in the DLLC (Iorns et al. 1965). Unknown trade-offs may exist in which the loss of forests to larger, more intense wildfires may reduce evapotranspiration, increasing infiltration Downscaled GCMs suggest that the DLCC may sustain climate change–induced reduction of precipitation (BOR 2012).

Adaptive responses to ecosystem management and climate changes have been recommended by SSI (2013), EcoAdapt (2013), and other organizations through the following rather simple strategic ecosystem resources management formula:

Resource Inventory → Assessment of Vulnerability → Planning →
Implementation → Feedback and Adjustment of Management Practices

This adaptive management formula accepts uncertainty and bases management decision-making on the best available scientific evidence, practices which are recommended here.

Conscientious management requires understanding about the distribution of ecosystem resources (Objectives 1 and 2), and also the use, status and vulnerability of those resources to climate change. Thus, an *a priori* understanding is needed of springs use and economic reliance on springs ecosystem goods and services within groundwater basins, because geography, ownership, and use may strongly affect springs management options.

Vulnerability assessment of springs ecosystems and SDS to climate change requires four sets of data that prior to the present study were not fully available: the distribution of springs

(Objective 1); the distribution of SDS (Objective 2); the population demands and uses to which springs are subjected; and 4) the status of the aquifers supporting those springs. While each dataset is needed to understand the vulnerability of springs to climate change, the absence of use data remains a substantial information gap, one that prevents basic understanding of the regional role and importance of springs ecosystem goods and services, both socioeconomically and in relation to biodiversity management. Below we address each of these datasets, and we use the resulting information to evaluate the geography of springs and SDS risks to climate change across the DLCC landscape.

Stage 1. What are the uses of springs in DLCC land units?

Past projects have revealed that many federal, state, Tribal, and private resource stewards use springs water for potable and livestock watering purposes (e.g., Grand Canyon Wildlands Council 2002, Ledbetter et al., in press), but there exists no regional estimate of the extent or distribution of such uses. Many of the USFS, BLM field stations, and many private ranches in northern Arizona use springs for potable water supplies, with more than 70% of sorings in northern Arizona and outside National Parks being ecologically impaired becuase of human uses (e.g., Ledbetter et al., in press), and with more than 10% of the water supply for the city of Flagstaff derived from springs (Young 2013). However, the uses of springs throughout the DLCC have not been compiled. Such information is critical to understanding the importance of springs and, hence, the level of preparedness needed to adapt to different climate change scenarios.

We conducted a general assessment of the ecological status and use to which DLCC springs are put by interviewing participating land and resource managers. We asked the city water managers of all large DLCC cities and 50 randomly selected small towns, as well as each collaborating agency in the DLCC landscape to quantify to the extent possible how the springs under their jurisdiction are used. We asked each participating resource manager the following questions:

1) How well do you know the distribution and ecological status of springs within your land management area (this may include the traditional cultural landscape of Native American Tribes)?
2) How many springs exist within your jurisdiction?
3) Who owns the springs water rights (e.g., agency versus allotment holders)?
4) How many of the following springs uses exist - residential domestic (potable), urban-potable, urban-industrial, rural livestock watering, wildlife water, recreational use, mining, fire suppression, not used, or other?
5) What is the ecological status of your springs?
6) Which springs are your highest management and restoration priority and why

Also, we held a springs valuation and use webinar on 3/26/2015 to further explore this topic with collaborating organizations.

We received limited responses on these requests. Water managers from large cities in the DLCC were most responsive, likely because cities have dedicated water managers. We received replies from 10 of the 50 randomly selected towns that we queried, but only a few federal land managers responded about the use of springs on their lands. Most respondents reported little use of springs, with only one city reporting more than 10% of its water derived from springs.

Nonetheless, direct survey data on springs in several large federal land units reveals that many managers and allotment holders on DLCC state and federal lands use springs for domestic and livestock watering purposes. However, it does not appear that such information has been compiled by federal or state managers. We know of several national parks in which springs provide the primary source of potable water, but those managers did not respond to our inquiries. Similarly, interviews with several state level water managers revealed little knowledge or concern for the use of springs: most concern was expressed about water rights and applications, not about economic uses of the springs. As a consequence, our springs map does not reveal use intensity or HUC-based economic value of springs. Learning more about the economic value of springs may require targeted interviews with specific individuals, rather than electronic or US Mail-based, or webinar-based inquiries.

Stage 2– Develop a landscape-based GIS Climate Change Risk Model: Comprehensive groundwater modeling of all hydrologic basins (or HUCs) in the DLCC region are not available, so surrogate hydrological indicators may provide insight into relationships between HUCs, human population growth and groundwater demand, aquifer depth, SDS, and potential climate changes. Using such information, a springs ecosystem climate change risk model may be developed. We compiled data to develop a landscape model of springs vulnerability to climate change based on the above products of this research, coupled with previously generated climate change analyses. The climate change risk model, designed at the 8-digit HUC scale was based on: 1) the DLCC springs distribution map (Objective 1); 2) the SDS distribution map (Objective 2); 3) several syntheses of down-scaled global circulation models; and 4) human population status and growth, which is likely related to groundwater demand. As stated in Stage 2, our HUC-based springs economic use data was insufficient for inclusion in this model.

We compiled the number and density of DLCC springs and SDS through Tasks 1 and 2 (above), and developed human population change and multi-model temperature and precipitation change data syntheses for each of the 144 HUCs in the DLCC. We ranked values for population, temperature, precipitation factors for each HUC. We are continuing to refine the results of the climate change risk model through the SSI website and webinar series. We generated maps of DLCC springs, and created individual maps on 2010 and 1990-2010 human population changes, as well as predicted temperature and precipitation changes in each HUC across the DLCC. Additional, specific methods and results are presented along with the electronically-available maps listed below:

Springs-dependent Species Data and Modeling

http://springs.maps.arcgis.com/apps/webappviewer/index.html?id=15b696f26b2f446fb9295e699c79c84b

Precipitation Change Modeling

Precipitation change ArcGIS editable online map: http://arcg.is/1hbPFNV
Precipitation change narrative:
http://springs.maps.arcgis.com/apps/webappviewer/index.html?id=83d65db07dab4e58a3ed589cf3087610
Variability in precipitation models: http://arcg.is/1FJ6rPY

Temperature Change Modeling

Temperature change ArcGIS editable online map: http://arcg.is/1FJ6mf8

Temperature change narrative:
http://springs.maps.arcgis.com/apps/webappviewer/index.html?id=5da768bd36ab44c1a37189d36c69638d

Variability in temperature change: http://arcg.is/1FJ6taC;
http://springs.maps.arcgis.com/apps/webappviewer/index.html?id=77ce0dc0e7af40ffb59f38cae521751e

Human Population Mapping

Population Density in 2010:
http://springs.maps.arcgis.com/apps/webappviewer/index.html?id=454c47abd1b24222b4c688e628f4037c

Population change, 1990-2010:
http://springs.maps.arcgis.com/apps/webappviewer/index.html?id=da2e97cf194a43e8ad93aadb877c9ef2

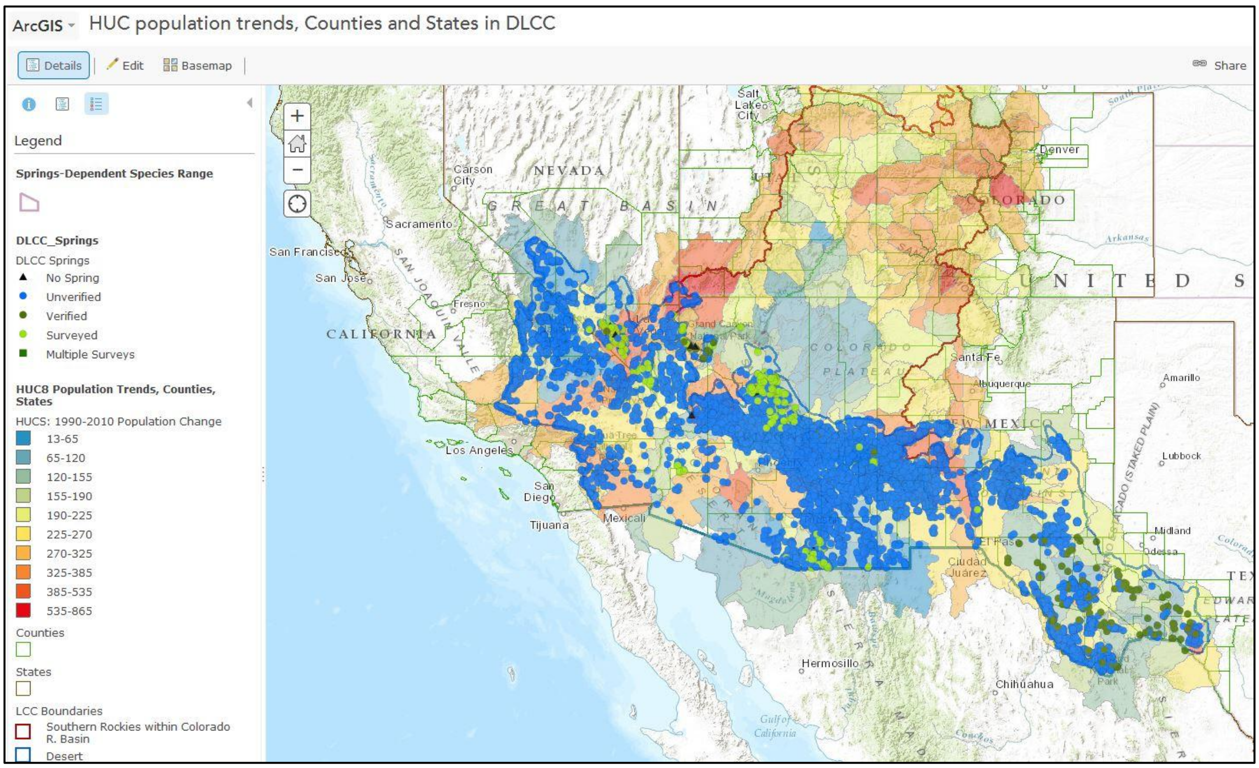

Figure 5 Interactive web map of springs in relation to population change within 8-digit HUCs from 1990 to 2010, and publicly available springs within the US portion of the DLCC.

Stage 3 – Test and Apply the Climate Change Risk Model: Following the mapping efforts described above, we analyzed the resulting data both individually across the DLCC landscape, and in a conservative rank-sum fashion against SDS number and density/km^2. We validated modeling results by randomly selecting half of the raw and more conservative ranked summed impacts metric of projected environmental change against the number, density, and area-adjusted density of SDS, and tested those results against the other half of the data.

The mean estimated number of SDS/HUC was relatively high, at 17.9 SDS/HUC, with a density of 0.004 SDS/km^2 across the DLCC (Table 3). Human population density/km^2 in 2010 was a highly variable as well, with 36 persons/km^2, ranging from 0 to 1,311/km^2, and population density/HUC doubled no average since 1990. Synthesis of all climate models reviewed indicated that, on average, air temperature is expected to increase 3˚C and precipitation is expected to decrease by 24.1 mm over the next 50 yr. We note that temperature and precipitation change are slightly positively related to HUC latitude, while precipitation change is slightly negatively related to longitude.

Table 3: Mean, minimum, maximum, median, and 95% confidence intervals for area, SDS species and SDS density/km^2, human population density/km^2 in 2010 and percent change from 1990-2010, and predicted 50-year maximum air temperature (˚C) and precipitation change (mm) among 144 8-digit HUCs in the DLCC.

Variable	log10(Area) (km^2)	No. of SDS/HUC	SDS Den/km^2	Population Density/km^2 2010	%Population Density/km^2 Change 1990 - 2010	Predicted Max Temperature Change (˚C)	Predicted Precipitation Change (mm)
Mean	3.68	17.9	0.004	36.0	204.8	3.03	-24.08
Min	2.68	0.0	0.000	0.0	0.0	2.29	-53.14
Max	4.41	121.0	0.021	1311.2	863.0	3.03	5.01
Median	3.69	12.0	0.002	1.6	181.6	2.73	-26.17
95% CI	0.05	3.3	0.001	23.1	19.2	0.02	2.10

DISCUSSION

Our data shown large increases in the DLCC human population from 1990-2010, and our synthesis of numerous published climate models predicts rising air temperature and decreasing precipitation across the DLCC over the next 50 yr. These changes appear to be more-or-less ubiquitous and may negatively affect springs by reducing available moisture, increasing evapotranspiration, likely decreasing infiltration, and increasing human demand for groundwater.

Our initial attempt to model and prioritize anthropogenic impacts on springs within surface drainage basin indicate that springs in all DLCC HUCs are at considerable risk due to the individual and combined impacts of population growth and climate change. Comparative modeling of randomly selected half versus all of raw and $\log_{10}$-transformed SDS richness and density data against raw or ranked total population and climate change score increase correlation coefficients from 0.01 to 0.02, levels that are virtually uninformative. Individual pairwise combinations generated similarly low, uninformative landscape-wide patterns.

Several possible explanations for these findings may exist, including: 1) erroneous basic assumptions (e.g., the relationship between future climate change and contemporary SDS distribution); 2) data or modeling errors; or 3) the ubiquity and severity of population and climate change impacts universalize risks to springs across HUCs. For the first, we consider our logic to be sufficient, as the factors considered appear to be sufficient to provide a conservative, ranked scoring system to evaluate and prioritize springs-related risks to the DLCC HUCs. For (2), we have evaluated the data carefully, and continue to refine species springs-dependent status, as additional information becomes available. However, downscaling GCMs in topographically complex terrain like the DLCC region is problematic, as elevation controls synoptic-scale as well as micro-scale climate. Too few springs have been equipped with weather sensors to allow testing of these downscaled GCMs across elevation and aspect against long-term monitoring data on microclimate at springs. Such an approach will be required to test the modeling structure we used, and which has generally been used to predict climate changes.

Reframed, the latter issue (3) simply posits that our data are sufficient, but that the human population demand and climate change variables place springs in DLCC HUCs at roughly equivalent risk over the next 50 yr. We observed considerable variation among temperature, precipitation, and human population change predictions across the HUCs, as depicted on the maps (above). Minimum and maximum predicted temperature and precipitation changes varied by 1.3- to 6.1-fold; while population density and growth varied non-synchronously nearly 3 orders of magnitude (Tabled 3). Although all variables were ranked for summation in an overall risk assessment, such magnitudes of variation may swamp interpretation of the risks projected for individual HUCs.

Implications of these findings include the suggestion that many SDS are at relatively high, short-term risk of habitat reduction or loss and extirpation/extinction of associated SDS. Large number of presently non-listed SDS may face elevated risk of extirpation or extinction, suggesting that more ESA listing may be likely in the future in the DLCC. It is noteworthy that of the southwestern species recognized as having gone extinct over the past century, nearly all have been SDS that lost critical habitat. These include species groups ranging from plants to springsnails and fish. Therefore, if these patterns of springs habitat loss continue, resource managers will pay more attention to springs and SDS in the future. Additionally, because endemism is higher at evolutionarily stable, deep-aquifer springs, our springs and SDS mapping data may provide insight into the distribution of those deep-aquifer springs. Such information can be used by managers to identify other similar springs and HUCs in which endemic or new SDS are likely to occur.

PROJECT MANAGEMENT

We began this project in September 2013 with an advertised for two positions - an MNA data management technician as well as an MNA intern. The intern we hired proved to be quite adept at many of the tasks required for both positions, and as the funding for the internship was limited to 16 weeks, we decided to shift some of the funding for the data management technician toward her. She left her position at the end of April 2014, and Marguerite Hendrie resigned in May for another job. Therefore, we initiated a search for another data management technician, hiring Monica Swihart (technician), Mr. Jeff Jenness (data management assistant), and our new intern, Jennifer Chavez. All positions have been part-time. Ms. Swihart left our employ for better opportunities in February 2015, and we subsequently replaced her with Molly Joyce. We hired a second intern for summer 2015 (Mr. Lance Murray), and also engaged summertime volunteer assistance through MNA both years. Through this process, we have remained on schedule and within budget.

During the initiation of this project in early 2015, MNA secured an approved overhead rate of 43.01%, increasing our MNA in-kind match to 22.1%. We received $30,345 of in-kind contributions from ESRI, or which we had $18,672 budgeted. The ESRI contributions included software, training, and discounted rates for maintenance and ArcGIS Online subscriptions. With these additional contributions, we added considerably more in-kind match to the project than originally expected.

CONCLUSIONS

The four objectives associated with this DLCC springs project were accomplished in a timely, credible, and appropriate manner, and the project was completed on time and at the proposed budget. We greatly appreciate the opportunity to work with the Bureau of Reclamation staff, and are impressed with the diligence and facilitation of the DLCC program. We hope that the methods and tools that we developed and presented here can be used through the LCC network, as springs and springs-dependent species are everywhere important ecological and economic resources.

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REFERENCES CITED AND OF RELEVANCE TO THE PROJECT

Abele, S.L., editor. 2011. Nevada Springs Conservation Plan. Springs Conservation Plan Working Group. The Nature Conservancy, Reno.

Alexander, P., L. Brekke, G. Davis, S. Gangopadhyay, K. Grantz, C. Hennig, C. Jerla, D. Llewellyn, P. Miller, T. Pruitt, D. Raff, T. Scott, M. Tansey, T. Turner. 2011. Reclamation, SECURE Water Act Section 9503(c) – Reclamation Climate Change and Water. U.S. Department of the Interior Bureau of Reclamation Report to Congress, Denver.

ALRIS. 1993. Springs. Arizona State Land Department, Arizona Land Resources Information System. Retrieved from http://www.land.state.az.us/alris/layers.html in February 2010.

AGIC. 2008. Springs – Natural Heritage Database. Arizona State Land Department, Arizona Land Resources Information System. Retrieved from http://agic.az.gov/portal/dataList.do?sort=theme&dataset=418 in June 2010.

AZGFD. 2010. Hatcheries. Retrieved from http://www.azgfd.gov/h_f/hatcheries.shtml%20 on 5/21/13

Bauer, P.W., P.S. Johnson, and S. Timmons. 2007. Springs of the Rio Grande Gorge, Taos County, New Mexico: Inventory, data report, and preliminary geochemistry. New Mexico Bureau of Geology and Mineral Resources Open-file Report 506.

Bauer, P.W. and P.S. Johnson. 2010. A rare, large artesian subaqueous spring in the upper Rio Grande. New Mexico Geology Vol 32 No. 1. 26-29.

Beckman, W.C. 1952. Guide to the Fishes of Colorado. Colorado Game and Fish Department, Denver.

Blinn, D.W. 2008. The extreme environment, trophic structure, and ecosystem dynamics of a large, fishless desert spring. Pp. 98-126 *in* Stevens, L.E. and V.J. Meretsky, editors. *Aridland Springs in North America: Ecology and Conservation*. University of Arizona Press, Tucson.

Brown, B.T.and S. Moran. 1979. An Inventory of surface Water Resources in Grand Canyon National Park, Arizona.

Brune, G. M. 1981. *Springs of Texas*. Texas A&M College.

Burke, K.J., K.A. Harcksen, L.E. Stevens, R.J. Andress, and R.J. Johnson. In press Collaborative rehabilitation of Pakoon Springs in Grand Canyon-Parashant National Monument, Arizona. Submitted to Eleventh Biennial Symposium on Research on the Colorado Plateau, U.S. Geological Survey, Flagstaff.

Clarkson, R.W. and J.C. Rorabaugh. 1989. Status of leopard frogs (*Rana pipiens* complex: Ranidae) in Arizona. The Southwestern Naturalist 34:531-538.

Davis, C.J., A.E. Springer, L.E. Stevens. 2011. Have arid land springs restoration projects been effective in restoring hydrology, geomorphology, and invertebrate and plant species composition comparable to natural springs with minimal anthropogenic disturbance?, *Collaboration for Environmental Evidence*, Systematic Review CEE 10-002, 72 p.

Fleishman, D. 2009. USDA Forest Service, Coconino National Forest, ESRI Shapefile.

Flora, S.P. 2004. Hydrogeological Characterization and Discharge Variability of Springs in the Middle Verde River Watershed, Central Arizona. Northern Arizona University MS thesis, Flagstaff

Gleick, P., H. Cooley, M.J. Cohen, M. Morikawa, J. Morrison, and M. Palaniappan. 2009. The World's Water: The Biennial Report on Freshwater Resources. Island Press, Washington.

Gleick, P. H. 2010. Bottled and Sold: The Story Behind Our Obsession with Bottled Water. Island Press, Washington.

Glick, P., B.A. Stein, and N.A. Edelson, editors. 2011. Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. National Wildlife Federation, Washington.

Grand Canyon Wildlands Council, Inc. 2002. Arizona Strip Springs, Seeps and Natural Ponds: Inventory, Assessment, and Development of Recovery Priorities. Grand Canyon Wildlands Council, Inc., Flagstaff, AZ. Available at http://springstewardship.org/PDF/ASSP%20final%20report%20020430.pdf.

Hallam, Valerie G. 2010. Detailed statistical analyses of fundamental properties of springs ecosystems in relation to their geomorphological and ecological diversity. Northern Arizona University MS thesis, Flagstaff.

Hansen, L. 2013. EcoAdapt : Meeting the Challenges of Climate Change. Website available online at: http://www.ecoadapt.org/; accessed 1 June 2013.

Hershler, R., H-P Liu, and L. E. Stevens. A new springsnail (Hydrobiidae: *Pyrgulopsis*) from the lower Colorado River basin. Submitted for publication to The Western North American Naturalist.

Iorns, W.V., C.H. Hembree, and G.L. Oakland. 1965.Water resources of the upper Colorado River basin. U.S. Geological Survey Professional Paper 441, Washington.

Klausmeyer, K. R., M. R . Shaw, J.B. MacKenzie, and D.R. Cameron. 2011. Landscape-scale indicators of biodiversity's vulnerability to climate change. Ecosphere 2: 1-18.

Knuttti, R. and J Sedláček. 2012. Robustness and uncertainties in the new CMIP5 climate model projections. Nature Climate Change 3:369–373.

Landwehr, J.M. and I.J. Winograd. 2004. A Devils Hole Primer. Retrieved from on http://water.usgs.gov/nrp/devils.html 5/2/11.

Langman, J.B., Sprague, J.E., and Durall, R.A., 2012, Geologic framework, regional aquifer properties (1940s–2009), and spring, creek, and seep properties (2009–10) of the upper San Mateo Creek Basin near Mount Taylor, New Mexico: U.S. Geological Survey Scientific Investigations Report 2012–5019, 96 p.

Ledbetter, J.D., L.E. Stevens, and A.E. Springer. 2012. Springs Inventory Database. Springs Stewardship Institute, Flagstaff.

Macholl, Jacob A. 2007. Inventory of Wisconsin's Springs. Retrieved from http://www.uwex.edu/wgnhs/wofrs/WOFR2007-03.pdf on 5/2/2011.

Minckley, W.L. 1973. *Fishes of Arizona*. Arizona Game and Fish Department, Phoenix.

Monroe, S.. 2011. Southern Colorado Plateau Network. NPS field data sheets, Flagstaff.

Mundorff, J.C. 1970. Major Thermal Springs of Utah. Utah Geological and Mineralogical Survey Bulletin 13.

Mundorff, J.C. 1971. Nonthermal Springs of Utah. USGS Water Resources Bulletin 16.

Nabhan, Gary Paul. 2008. Foreword. Stevens, L.E. and V.J. Meretsky, editors. *Aridland Springs: Ecology and Conservation*. University of Arizona Press. Tucson.

Nevada Springs Restoration Workshop Committee. 2012. A Restoration Guide for Nevada, Great Basin and Mohave/Sonoran Desert Springs. Available online at: http://www.springstewardship.org/PDF/NevadaSpringsRestoration.pdf (accessed 7 June 2013).

Odum, H.T. 1957. Trophic structure and productivity of Silver Springs, Florida. *Ecological Monographs* 27(1).

Rice, Steven E. 2007. Springs as Indicators of Drought: Physical and Geochemical Analyses in the Middle Verde River Watershed, Arizona. Northern Arizona University MS thesis, Flagstaff.

Runck, C. and D.W. Blinn. 1994. Role *of Belostoma bakeri* (Heteroptera) in the trophic ecology of a fishless desert spring. Limnology and Oceanography. 39(8), 1994, 1800-1812. Retrieved from http://www.aslo.org/lo/toc/vol_39/issue_8/1800.pdf on 5/2/11.

Sada, D.W. and J. Nachlinger. 1996. Spring Mountains Ecosystem: Vulnerability of Spring-Fed Aquatic and Riparian Systems to Biodiversity Loss. Unpublished report to U.S. Fish and Wildlife Service, Las Vegas, Nevada.

Sada, D.W., 2008a. Great Basin riparian and aquatic ecosystems. Collaborative Management and Research in the Great Basin. Examining issues and developing a framework for action, U.S. Forest Service, Rocky Mountain Research Station, Reno.

Sada, D.W., 2008b. Synecology of a springsnail (Caenogastropoda: Hydrobiidae) assemblage in a western U.S. thermal spring province. The Veliger 50:59-71.

Schaller, E.M. 2013. Investigations into groundwater springs ecosystems across western North America in two studies – stable isotopic flow determination and geochemical impacts on geomorphology and vegetation cover. Northern Arizona University MS thesis, Flagstaff.

Scott, T.M., G.H. Means, R.P. Meegan, R.C Means, S.B. Upchurch, R.E. Copeland, J. Jones, T. Roberts, A. Willet. 2004. Springs of Florida. Florida Geological Survey, Bulletin No. 66, Tallahassee, FL.

SCPN 2007. Northern and Southern Colorado Plateau Springs Inventory Site Summaries, National Park Service data.

Springer, A.E., L.E. Stevens, J.D. Ledbetter, E.M. Schaller, K.M. Gill, and S.B. Rood. 2014. Ecohydrology and stewardship of Alberta springs ecosystems. Ecohydrology. DOI: 10.1002/eco.1596.

Springs Stewardship Institute. 2013. Ecohydrology of Springs on Kaibab National Forest to Support Forest Planning. USFS Agreement #10-CS-11030700-023.

Stevens, L.E. 2007a. Water and biodiversity on the Colorado Plateau. Plateau: The Land & People of the Colorado Plateau 4(1): 48-55.

Stevens, L.E. 2007b. A review of invertebrate species of management concern on five northern Arizona forests: final report. Museum of Northern Arizona, Flagstaff.

Stevens, L.E. 2008 Every last drop: future of springs ecosystem ecology and management. Pp. 332-346 i*n* Stevens, L.E. and V. J. Meretsky, editors. *Aridland Springs in North America: Ecology and Conservation*. University of Arizona Press, Tucson.

Stevens, L.E., and V J. Meretsky, editors. 2008. *Aridland Springs in North America: Ecology and Conservation*. University of Arizona Press, Tucson.

Stevens, L.E. and J.T. Polhemus. 2008 Biogeography of aquatic and semi-aquatic Heteroptera in the Grand Canyon ecoregion, southwestern USA. Monographs of the Western North American Naturalist 4:38-76.

Stevens, L.E., and A.E. Springer. 2004. A conceptual model of springs ecosystem ecology: Task 1B Final Report, NPS Cooperative Agreement Number CA 1200-99-009. National Park Service, Flagstaff. Available at http://springstewardship.org/model.html.

Stevens, L.E., and A.E. Springer. 2008. Spheres of discharge of springs. Hydrogeology Journal DOI 10.1007/s10040-008-0341-y.

Stevens, L.E., A.E. Springer, and J.D. Ledbetter. 2011. Inventory and Monitoring Protocols for Springs Ecosystems. Available at http://springstewardship.org/PDF/Springs_Inventory_Protocols_110602.pdf.

Sublette, J.E., M.D. Hatch, and M.Sublette. 1990. *The Fishes of New Mexico*. University of New Mexico Press, Albuquerque.

USGS. 2012. The Colorado River Basin Focus – Area Study (http://pubs.usgs.gov/fs/2012/3114/fs2012-3114.pdf) Accessed 6/5/2013.

USGS. 2013. National Hydrography Dataset (NHD for Arizona, California, Nevada, Utah, New Mexico, and Texas 5/14/13 available at ftp://nhdftp.usgs.gov/DataSets/Staged/States/FileGDB/HighResolution/ .

UDWR. 2011. Fish Hatcheries. Retrieved from http://wildlife.utah.gov/hatcheries/ on 5/21/13.

US Bureau of Reclamation. 2011. Climate Change and Water 2011. Basin Report: Rio Grande.

US Bureau of Reclamation. 2012. Colorado River Basin Water Supply & Demand Study Final Study Reports. Available online at: http://www.usbr.gov/lc/region/programs/crbstudy/finalreport/; accessed 1 June 2013.

USDA Forest Service. 2012. Groundwater-Dependent Ecosystems: Level I Inventory Field Guide: Inventory Methods for Assessment and Planning. Available online at: http://www.fs.fed.us/geology/GDE_Level_I_FG_final_March2012_rev1_printing.pdf.

US Fish and Wildlife Service. 2011. The Boundary of the Desert LCC. U.S. Fish and Wildlife Service Landscape Conservation Cooperatives: U.S. Fish & Wildlife Service, USA. Retrieved from http://www.fws.gov/GIS/data/national/FWS_LCC.zip on 5/20/13.

Wagner, V. T and D.W. Blinn. 2000. Montezuma Well: The Living Desert Oasis. Arizona Roadside Environments website. Retrieved from http://www.nau.edu/~envsci/naeerc/meresi/research/sites/montezuma.html on 5/2/11.

Wallace, R.L. and D.W. Zaroban. 2013. Native Fishes of Idaho. American Fisheries Society. North Bethesda.

Williams, D. 2009. More fish, more fun: Revitalized NM hatcheries see bright future. Retrieved from http://www.wildlife.state.nm.us/recreation/fishing/on 5/29/2013.

White, W.E. and G.E. Kues. 1992. Inventory of springs in the state of New Mexico. U. S. Geological Survey, Open-File Report 92-118:1-228.

Young, E. 2013. Flagstaff water demand: urban water demand roundtable. Presentation to the City of Flagstaff. Available online at: http://dcdc.asu.edu/docs/dcdc/website/documents/15_ErinYoung_Water%20Demand%20Workshop%2018%20APR%202013%20EMY.pdf; accessed 1 June 2013.