Spring Health Monitoring for the 4 Forest Restoration Initiative 2019 Annual Progress Report

USFS Cost Share Agreement #19-CS-11030400-015

Report prepared by:

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Williams, AZ 86046

31 March 2020

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Acknowledgements

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INTRODUCTION

Four National Forests—Kaibab, Coconino, Apache-Sitgreaves and Tonto National Forests, are engaged in the Four Forest Restoration Initiative (4FRI), a collaborative, landscape-scale initiative designed to restore 2.4 million acres of fire-adapted ponderosa pine ecosystems in northern Arizona. The greater part of the 4FRI restoration effort consists of thinning forests through felling trees or using prescribed burning. In addition, 4FRI also encompasses a diversity of other restoration actions, which include monitoring to detect changes in watershed health as the program is implemented. Springs ecosystems, while frequently undervalued, are vital components of watersheds; indeed, the hydrologic and ecological condition of the springs within a watershed serve as indicators of overall watershed health. Due to the ecological importance of springs habitats and the often high levels of biodiversity that they support, the Museum of Northern Arizona's Spring Stewardship Institute (SSI) is collaborating with the US Forest Service and the Comprehensive Implementation Working Group (CIWG), a stakeholder group associated with 4FRI, to develop and implement the 4FRI Springs Health Monitoring Program.

SSI is an initiative of the 501c3 private, non-profit Museum of Northern Arizona (MNA), which was founded in 1928. SSI's mission is to improve understanding and stewardship of springs ecosystems. SSI's objectives are to create and disseminate information, tools, protocols, and advisement to enhance natural and cultural resource management of springs ecosystems. SSI's work throughout the 4FRI region will advance the knowledge and understanding of springs ecological integrity as a component of ecosystem management in this landscape-scale restoration effort.

The purpose of the 4FRI Spring Health Monitoring Program is to document hydrologic and ecological changes that occur at springs as a result of 4FRI restoration actions. This five-year monitoring program will document and compare ecological and hydrologic conditions at 56 springs, half of which are located within the 4FRI treatment boundary and half of which are located outside the treatment boundary and serve as a control group. As forest restoration treatments are completed and trees are removed from large swaths of the northern Arizona landscape, we expect that springs discharge and flow duration may increase. With increases in springs discharge, we predict that the spatial extent of springs-dependent ecosystems will expand and floral and faunal diversity at these ecosystems will increase. Furthermore, because 4FRI is implementing major landscape-scale changes to northern Arizona forests, we also anticipate that unexpected ecological changes may follow. This springs monitoring program will help land managers quickly understand the broad and potentially unanticipated impacts of 4FRI influences on watershed condition.

This report presents data from the first year of this five-year monitoring program. The data presented here provide a baseline for assessing hydrologic and ecological changes to springs ecosystems resulting from implementation of the Four Forest Restoration Initiative and in relation to climate variation during this study period.

METHODS

Overview

SSI designed this springs monitoring plan in collaboration with the US Forest Service and the CIWG. The full monitoring plan (Schenk *et al.* 2019) was submitted and accepted by the US Forest Service in June 2019. Here we present a summary of the monitoring plan, with emphasis on the tasks completed and data collected during year one.

In 2019, SSI staff completed study site selection and conducted initial visits at 56 springs located across the Kaibab and Coconino National Forests. At each site, the field crew completed these three tasks, each of which is described in greater detail below:

1. Conduct and review Level II springs inventories for the 56 springs located across the Kaibab and Coconino National Forests.
2. Install HOBO Tidbit data logger devices, submerged in at least one centimeter of water where water is present, with the specific placement reported on and the device flagged, at the sites for yearly water level assessment.
3. Update SSI's Springs Online Database (http://springsdata.org/) with the new data from the above inventories and conduct quality control checks on all data entered.

During years two through four of this monitoring program, SSI staff will coordinate volunteers to download hydrologic data from all HOBO Tidbit dataloggers annually, measure discharge at each spring with flowing water, document habitat area change, and document springs invertebrate assemblages to quantify faunal diversity.

During year five of this monitoring program, SSI field crews will conduct a comparative Level 2 springs inventory at each of the 56 springs. SSI staff will analyze the ecological and hydrologic data from all five years of the monitoring program. They will produce a report that describes changes recorded over the study period, and compares the treatment group to the control group to determine whether 4FRI treatments have resulted in detectible changes in springs ecohydrology.

Site Selection

The study area was defined within the Williams Ranger District of the Kaibab National Forest and the Mogollon Rim and Flagstaff Ranger Districts of the Coconino National Forest, at elevations ranging from 1,829 and 2,591m (6,000-8,500 ft; Fig. 1). SSI staff identified all springs reported in the study area, using the Springs Online database (springsdata.org). Study sites were selected from that set of potential springs using a stratified design developed in coordination with the US Forest Service and the CIWG (Table 1). The sample size of 56 sites was determined using a power analysis, which is detailed in the full monitoring plan (Schenk *et al.* 2019). Half (28) of the springs are located within the 4FRI treatment boundary and half (28) of the springs are located nearby but outside of the treatment boundary and serve as a control group. Sites are stratified according to parent rock type and spring type. The two most common parent rock types in the study area, igneous (basalt) and sedimentary (limestone), are equally represented among the selected springs. The three most common spring types in the study area are rheocrene springs, hillslope springs, helocrene springs. Rheocrene springs, or springs emerging into the bed of a surface water channel such as a river or dry wash, were not included in the study design because upstream surface water contributions strongly shape the ecology and hydrology of this spring type. The other two common spring types, hillslope springs and helocrene springs, are equally represented among the selected springs.

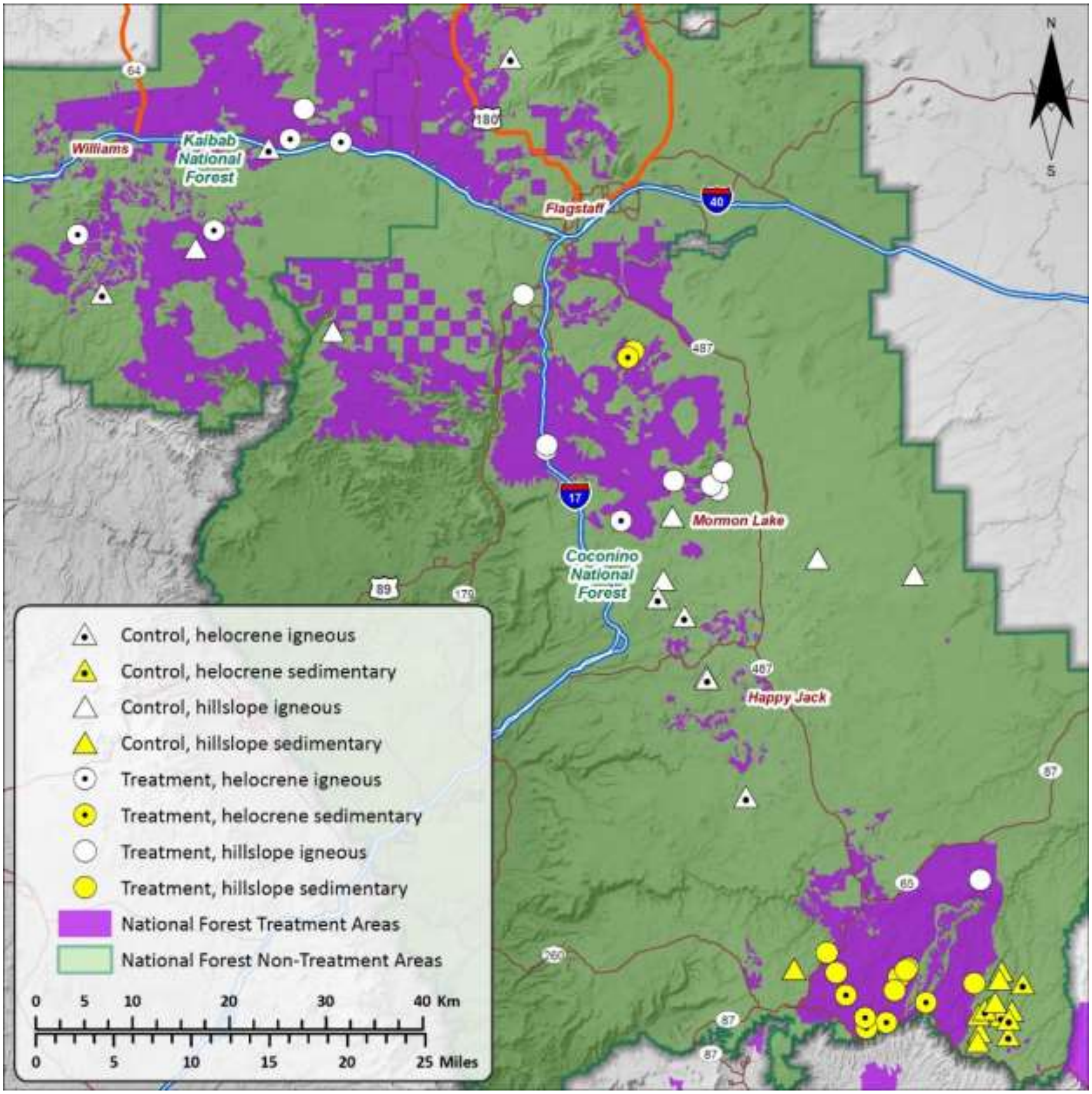

Figure 1. Map showing the 56 study sites in the 4FRI Spring Health Monitoring Study.

In several cases, SSI staff visits to a pre-selected study site revealed that the spring type had been misidentified in Springs Online, disqualifying it from the study design. In those cases, a replacement spring was selected with the correct lithology, spring type, and treatment status that was located closest to the rejected spring.

The final list of monitoring sites, with geographic coordinates and elevations, is included as Appendix A.

Table 1. The stratified design used for monitoring site selection. All study sites are located in the Kaibab National Forest (Williams RD) or Coconino National Forest (Mogollon Rim or Flagstaff RD) between 1,829 and 2,591 m (6,000 and 8,500 ft) elevation.

Spring Type	Primary Lithology	Total
Treatment		
Helocrene	Igneous	7
Helocrene	Sedimentary	7
Hillslope	Igneous	7
Hillslope	Sedimentary	7
Control Group		
Helocrene	Igneous	7
Helocrene	Sedimentary	7
Hillslope	Igneous	7
Hillslope	Sedimentary	7
Total		**56**

Task 1: Level II Spring Inventories

The SSI field inventory team for this project included wildlife biologists, botanists, hydrologists, field technicians, and trained volunteers. All 56 sites were inventoried using the SSI Level 2 Springs Inventory Protocol (Stevens *et al.* 2016b; Fig. 1). The Level 2 protocol is a rapid assessment method through which the springs inventory team quantifies a suite of physical and biological variables to describe, as completely as possible, ecosystem structure, characteristics, function, and anthropogenic impairments. Data are collected to describe site geography and geomorphology, springs discharge rate and geochemistry, vegetation composition and structure, and fauna. The protocol also includes an assessment of ecological condition and human impacts.

Below we provide a brief summary of the methods used to conduct a Level 2 inventory; much more information is presented in the full protocol document (Stevens *et al.* 2016b), available online at http://docs.springstewardship.org/PDF/ProtocolsBook.pdf.
For physical, chemical, and geographic data, the SSI Level 2 inventory protocol incorporates standard techniques of the U.S. Geological Survey and the U.S. Environmental Protection Agency for specific application to single-visit rapid inventory and assessment methods.

Geography and Geomorphology: The inventory crew documented site geography by recording the latitude, longitude, and elevation of the spring source using a GPS unit, and recording the unit's estimated positioning error. They also recorded the geopolitical status and land use of the springs ecosystem, including the country, state, county, landowner, and land unit detail.

The crew documented the site's geomorphology by identifying distinct geomorphic microhabitats within the springs-influenced zone. They described the slope, aspect, moisture level, and soil particle size distribution of each microhabitat. One member of the crew drew a sketch-map of the springs ecosystem to illustrate the location and approximate size of each geomorphic microhabitat and documented where certain measurements and photographs were taken. A scaled sketch-map that includes identifiable hard features (e.g., rocks, tree stumps, other unchanging features) allows subsequent inventory crews to promptly determine the area of springs habitat previously inventoried, and to determine where measurements were taken in the past, which is important for repeatability.

The inventory crew measured the topographically-based solar radiation budget at each spring source using a Solar Pathfinder. This instrument measures mean annual sunrise and sunset time on a template, which is used to calculate the average annual photosynthetically available solar radiation at the site (Solar Pathfinder 2016).

Site geography and geomorphology were further documented using photography. At each site, the inventory crew photographed the spring source, other major microhabitats such as runout channel or pool, and when possible, took at least one photograph that captured the entire spring ecosystem.

Springs Discharge: Throughout the project, crews used several different methods to measure springs discharge. Based on the flow volume and geomorphic setting, SSI staff selected the most appropriate technique for measuring the discharge. However, at many sites flow measurement was not possible, due to absence of water, standing water (e.g., a pond with no outflow), or diffuse outflow (e.g., in a ciénega). The most common method for measuring spring flow is the volumetric, or timed flow capture method, wherein the crew hydrologist focuses the spring flow through a pipe, and records the rate at which flow is captured (the discharge).

Water Quality: The inventory crew measured field geochemistry parameters *in-situ* as close to the source as possible for springs that had flowing or standing water at the time of the inventory. They measured geochemistry before the water was disturbed by biological or substrate sampling. They used a handheld multi-parameter probe to measure water temperature, pH, specific conductance, and total dissolved solids. They used a test kit to measure alkalinity. When water flowed from a discrete source, they used a test kit to measure dissolved oxygen concentration. Crews calibrated water quality probes daily using, at minimum, a two-point pH calibration and a one-point electrical conductance calibration.

Vegetation: The botanist quantified vegetation composition and structure by visually estimating the percent cover of each plant species within a each microhabitat. Cover was recorded separately within these seven cover strata: aquatic, non-vascular (e.g., moss, liverwort), ground (herbaceous dicots or graminoids), shrub (0-4 m woody plants), middle canopy (4-10 m woody), tall canopy (>10 m woody), and basal cover of tree trunks emerging from the ground. Plant species designations and native or introduced status are in accordance with the USDA-PLANTS database (2020).

Fauna: The inventory crew recorded all evidence of wildlife and sign observed within and adjacent to the springs ecosystem, including tracks, scat, and visual observation. Where possible, they collected aquatic and wetland invertebrates using aquarium nets and forceps into 80% ethyl alcohol sampling jars.

Assessment: The inventory crew applied SSI's Springs Ecosystem Assessment Protocol (SEAP; Stevens *et al.* 2016a) to assess site condition and record human impacts. Using the SEAP protocol, the crew evaluated the condition of each spring in five categories of information, including four natural resource categories (aquifer/water quality, geomorphology, habitat, and biota), and a fifth category called "freedom from human influences." Within this category, the crew assessed the springs ecological condition and risk levels in relation to human alteration in the following categories: surface water quality, flow regulation, roads/ trails/ railroads, fencing, construction, livestock herbivory, recreational impacts, adjacent landscape conditions, and fire. At each springs ecosystem, the crew evaluated condition and risk in each category on a 0 to 6 scale. For the site condition assessment, a score of 0 indicates extremely poor condition and 6 indicates a pristine condition. For the risk assessment, a score of 0 indicates no risk whatsoever to the springs ecosystem, and 6 indicates extremely high risk (and likely unrecoverable conditions) to the springs ecosystem. The inventory crew classified springs with condition scores below 3.5, and risk scores above 2.5 as "impaired" in the category receiving the poor condition or high risk score. These data can be used to develop management plans (e.g., Stevens et al. 2016a). Following the inventory, the crew recorded the amount of time spent inventorying the spring.

Task 2: Hobo Tidbit MX Temp 400 and Temp 50000 Installation

Each site was instrumented with a HOBO Tidbit MX Temp logger, set to record temperature and presence or absence of water hourly. These will be maintained over the course of the 5-year project. These devices are configured using a smart phone and data will be uploaded annually. Each HOBO Tidbit was zip-tied to a piece of flagged rebar and installed near the source in shallow water, where present. At dry springs, the crew selected a location close to the source that appeared likely to be inundated in the future. Because of the need to access these small devices annually, the crew documented the location of each Hobo Tidbit installation in three different formats: they wrote a description on a field sheet, they marked the location on a sketchmap, and they took photographs. All of these data are available on Springs Online.

Task 3: Information Management and Spring Online Data Entry

In the field, the inventory crew recorded all inventory data on standardized field sheets, which were labeled and placed into site folders. Upon returning to the SSI laboratory, staff archived the field sheets by scanning them, downloaded spatial data from GPS units, and downloaded site photos. Once this initial post-field data management was completed, SSI staff entered the data and uploaded photographs and sketch-maps into Springs Online. This relational MySQL database is stored on a dedicated server at the Museum of Northern Arizona and is backed up hourly. Once data were entered, the staff conducted two rounds of quality control procedures using standardized methods. Plant specimens were identified by the team botanist, and specimens of sufficient quality were archived at the Museum of Northern Arizona's McDougall Herbarium. Invertebrate specimens were identified to the extent possible by Dr. Larry Stevens. These specimens are archived in the Museum of Northern Arizona's Invertebrate Collection as voucher specimens for this project.

Standardized inventory summary reports were exported from the Springs Online database; these reports are attached as Appendix B.

RESULTS

Study Sites

Of the 56 study sites, 8 are located in the Kaibab National Forest, Williams Ranger District. The remaining 48 springs are located in the Coconino National Forest, with 16 springs in the Flagstaff Ranger District and 32 springs in the Mogollon Rim Ranger district (Fig. 1). Three of springs in the treatment group lie outside of the treatment boundary, but all are less than 50 m away from the treatment boundary and have upstream watersheds within the treatment area (Fig 2). The three outlying springs are Dairy (26 m from the treatment boundary), Trotting Turkey (27 m), and Clark (41m).

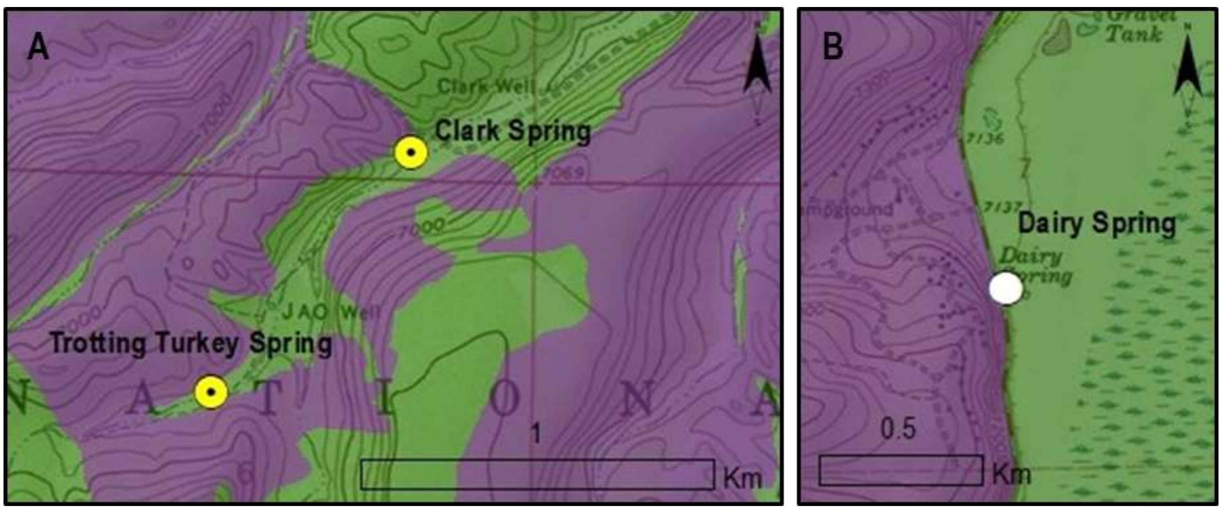

Figure 2. Topographic maps showing three springs which were classified in the treatment group but are located just outside the treatment area, shown in purple. Trotting Turkey Spring and Clark Spring are 27 m and 41 m from the treatment boundary, respectively (A), and Dairy Spring is 26 m from the treatment boundary (B). All three springs are immediately downslope from the treatment boundary.

Task 1: Level II Spring Inventories

Task Completion: During the 2019 field season, SSI field crews completed Level 2 inventories at 39 springs on the 4FRI springs health monitoring site list. The remaining springs on the list had been inventoried within the previous three years using the Level 2 protocol, and therefore were not re-inventoried in 2019. This section summarizes the baseline dataset from all 56 study sites, including those inventoried in 2019 and those inventoried in earlier years.

Geography: Springs in the treatment group ranged in elevation from 2,046 to 2,311 m, and springs in the control group ranged from 1,947 m to 2,491 m in elevation. Approximately 22,039 m^2 of springs-dependent habitat were inventoried and mapped.

Spring Discharge: The hydrologist measured springs discharge at 35 of the 56 springs and provided visual estimates of flow at 3 springs where flow rate was too low and diffuse to measure. At the remaining 18 springs, the hydrologist could not measure flow because the flow was too diffuse to measure (4 springs), the flow rate was too low to measure (1 spring), the only surface water was standing, not flowing (6 springs), or the spring was completely dry (7 springs).

Where flow was measured, the flow rates ranged from 0.003 L/s to 1.5 L/s, and the mean flow rate was 0.25 L/s. Flow was measured at fewer springs in the treatment group compared to the control group, but mean and median flow rates in the two groups were similar (Table 2). Visual estimates of flow in the control group were 0.01 L/s (Wilson Spring) and "less than 0.1 L/s" (Jones Spring). In the treatment group, the flow rate at T-Six Spring was visually estimated at 0.01 L/s.

Table 2. Number of springs where flow was measured during year 1 of the spring ecological integrity monitoring study (n), and the mean, minimum, and maximum of reported flow rates reported at springs in the treatment and control groups. This table only reports data on springs where it was possible to measure flow.

		-------Spring Flow Rate (L/s)-------			
	n	**Min**	**Max**	**Mean**	**Median**
Treatment	13	0.0027	1.5	0.23	0.12
Control Group	22	0.014	1.0	0.26	0.13
All Sites	**35**	**0.0027**	**1.5**	**0.25**	**0.12**

Water Quality: The hydrologist measured pH, conductivity, and water temperature at 48 springs. The remaining eight springs lacked surface water at the time of the inventory, so it was impossible for hydrologist to take water chemistry measurements. The hydrologist measured dissolved oxygen concentrations at 42 springs. Dissolved oxygen measurements are generally taken in flowing emergent water, so the hydrologist does not complete that measurement if only standing water is present at the site.

Specific conductance, pH, and water temperature were all slightly higher in the treatment group compared to the control group (Table 3). However, the differences between the two groups are likely not great enough to be considered biologically significant. Interestingly, the sedimentary (primarily limestone) sites did not substantially differ from the igneous sites in pH, and specific conductance was higher at the igneous sites compared to the limestone sites. Dissolved oxygen did not substantially differ among treatment groups and geology types.

Table 3. Baseline water chemistry results for 48 springs inventoried for the springs ecological integrity monitoring study, reported by treatment group and parent rock type.

	----pH----			Specific Cond. (µs/cm)		Water Temp (°C)		Dissolved O_2 (mg/L)		
	n	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**n**	**Mean**	**SE**
Treatment Group										
Igneous	10	6.6	0.25	280	71	18	2.2	8	5.4	1.1
Sedimentary	9	6.6	0.19	237	46	12	1.3	7	4.0	0.86
All Treatment	21	6.6	0.14	245	40	15	1.4	17	4.7	0.68
Control Group										
Igneous	13	7.3	0.26	410	173	14	1.2	11	4.5	0.55
Sedimentary	14	7.1	0.15	291	29	11	1.4	14	5.4	0.52
All Control	27	7.2	0.15	353	90	12	0.93	25	5.0	0.38
All Sites	**48**	**6.9**	**0.11**	**306**	**54**	**13**	**0.84**	**42**	**4.9**	**0.35**

Vegetation: Field crew detected 355 plant taxa at the 56 springs ecosystems. Of these plant taxa, 270 were identified to the species level. The number of plant species recorded at each springs ecosystem was slightly lower among the treatment sites compared to the control sites (Table 4). The percent of plant taxa coded as "wetland" or "wetland/riparian" at each springs ecosystem was similar among the control and treatment groups, at 34% (Table 4).

Table 4. Mean number of plant taxa, plant taxa identified to species, and wetland or wetland/riparian taxa recorded at springs ecosystems in the treatment group, control group, and all sites, with standard error corresponding to each mean. The percent of plant taxa coded as wetland or wetland/riparian is reported in the final column.

	No. Plant Taxa per Spring		Taxa Identified to Species Level		No. Wetland or Wetland/Riparian Taxa		% Wetland or Wetland/ Riparian
	Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	
Treatment Group	25.5	1.3	18.8	1.2	8.6	0.8	34%
Control Group	26.5	1.3	21.6	1.2	8.9	0.7	34%
All Sites	**26.0**	**0.9**	**20.3**	**0.9**	**8.7**	**0.5**	34%

Fauna: The inventory crew recorded 65 different vertebrate taxa at 42 of the 56 sites. Of these, 3 taxa were amphibians, 7 were reptiles, 39 were birds, and 16 were mammals (Table 5).The biologist observed more vertebrate taxa at springs in the treatment group compared to the control group, both in terms of the average number of taxa observed at each springs ecosystem (3.1 taxa per spring at treatment sites vs. 1.7 per spring at control sites), and in terms of the total number of birds, mammals and reptiles observed in each treatment group (Table 5).

Table 5. Total number of springs where vertebrate fauna were detected; mean and standard error of vertebrate taxa per springs ecosystem, and number of amphibian, bird, mammal, and reptile taxa recorded at springs in the treatment and control groups.

	No. Springs with Verts Recorded	**No. Vert. Taxa per Spring**		**-------------Total No. Vert. Taxa-------------**			
		Mean	**SE**	**Amphibian**	**Bird**	**Mammal**	**Reptile**
Treatment Group	23	3.1	0.5	2	29	11	6
Control Group	19	1.7	0.5	2	21	8	4
All Sites	**42**	**2.3**	**0.4**	**3**	**39**	**16**	**7**

The inventory crew recorded 185 invertebrate taxa at 44 sites. A total of 82% of invertebrate taxa belonged to nine orders, including highest diversity within Coleoptera (beetles), Diptera (flies), and Hemiptera (true bugs; Table 6). The inventory crew recorded invertebrates at an equal number of control and treatment springs (22 springs in each group) and reported slightly higher invertebrate diversity at the control sites compared to the treatment sites (Table 7).

Table 6. Number of taxa recorded in the nine invertebrate orders with the highest diversity and the representation of each order in the 4FRI Springs Health Monitoring baseline dataset.

Order	**No. taxa recorded**	**Representation (%)**
Coleoptera (beetles)	34	18
Diptera (flies)	27	15
Hemiptera (true bugs)	22	12
Hymenoptera (wasps, bees,	19	10
Lepidoptera (moths, butterflies)	18	10
Odonata (dragonflies, damselflies)	13	7
Araneae (spiders)	7	4
Trichoptera (caddisflies)	7	4
Plecoptera (stoneflies)	5	3

Table 7. Number of springs with invertebrate records in the 4FRI Spring Health Monitoring baseline dataset and the mean number of invertebrate taxa recorded per spring, with standard error, in the treatment and control groups.

	No. Springs with Inverts Recorded	No. Invert. Taxa per Spring	
		Mean	SE
Treatment Group	22	7.4	1.6
Control Group	22	8.1	1.7
All Sites	**44**	**7.7**	**1.2**

Most invertebrate specimens were collected through opportunistic sampling; however, the biologist completed quantitative benthic sampling at one spring, Griffiths Spring. In two repetitions (reps), the biologist recorded 14 taxa. The most abundant were *Hesperophylax* (limnnophild caddis fly larvae) with 22 individuals, Simuliidae (black flies) with 21 individuals, and Dytiscidae (predaceous diving beetles) with 5 individuals.

Assessment: The inventory crew used the Springs Ecosystem Assessment Protocol (SEAP; Stevens *et al.* 2016a) to quantify the ecological condition and risk at 55 of the 56 springs. One of the inventories conducted prior to 2019 was missing SEAP data, but the inventory crew will complete a SEAP assessment on that site in 2020. Among natural resource data categories, more springs in the treatment group were assessed as having impaired condition and elevated risk, compared to the control group (Table 8). This trend is driven by springs in the treatment area being assigned lower condition scores in the water quality and aquifer and geomorphology categories. In the SEAP protocol, springs are scored lower if they are dry, and treatment sites in this study tended to be drier than control sites, on average, in 2019: the hydrologist was able to measure flow at 13 springs in the treatment group and 22 springs in the control group (Table 2). Other sources of impairment at many sites were springs developments, particularly for livestock (e.g., cattle tank development, which dramatically altered site geomorphology), as well as adjacent roads and trampling by ungulates.

Task 2: Hobo Tidbit MX Temp 400 and Temp 50000 Installation

The inventory crew installed one Hobo Tidbit datalogger at each springs ecosystem. Descriptions of each installation location are included in Appendix B. The inventory crew will return to download the data during the 2020 field season.

Task 3: Information Management and Spring Online Data Entry

All data collected in 2019 have been entered into Springs Online and are available to users with appropriate permissions for review. Please visit http://springsdata.org/ to create a user account if you are interested in accessing this geocollaborative online database. All data are exported nightly into a geodatabase used for data analysis and planning. Springs Online is hosted on a dedicated server at the Museum of Northern Arizona, and that server stores the geodatabase. The system is backed up offsite on an hourly basis, and the geodatabase is updated nightly. All data have been exported into site summary reports (Appendix C).

Table 8. Springs Ecosystem Assessment Protocol mean category scores ±1 standard error, and the number and percent of springs ranked as impaired. In each category, spring condition was ranked on a 0-6 scale, with 6 indicating pristine condition, and spring risk was evaluated on a 0-6 scale with 6 indicating extremely high risk. Springs were considered impaired in a category if the condition score in that category was lower than 3.5, or if the risk score was higher than 2.5. In the treatment group, n=28 sites were assessed, and in the control group, n=27 sites were assessed.

		Mean Score +/- 1SE		No. Impaired Springs		% Impaired Springs	
Context	Variable	Trtmt	Control	Trtmt	Control	Trtmt	Control
Condition	Water Quality & Aquifer	3.4± 0.2	3.9± 0.1	12	7	43	26
	Geomorphology	3.5± 0.2	3.9± 0.2	13	8	46	30
	Habitat	3.8± 0.1	3.8± 0.1	9	8	32	30
	Biota	4.2± 0.1	4.3± 0.1	4	2	14	7
	Natural Resources - Overall	3.7± 0.1	4.0± 0.1	8	7	29	26
	Freedom of Human Influence	4.3± 0.1	4.4± 0.2	4	4	14	15
Risk	Natural Resources - Overall	2.5± 0.1	2.2± 0.1	15	8	54	30
	Freedom of Human Influence	2.4± 0.1	2.2± 0.2	10	8	36	30

DISCUSSION

Treatment vs. Control Springs

The data presented here represent the first year in a five-year monitoring study. In this baseline dataset, several differences between the springs in the treatment group and the control group are apparent. Springs in the treatment group were drier on average than those in the control group. This is evidenced by the fact that hydrologists were able to measure discharge at fewer springs in the treatment group. The reasons hydrologists failed to measure flow were all related to a lack of flowing water. In some cases, the spring was completely dry and in other cases flow was too limited or too diffuse to capture and measure. Other notable differences between the two groups of springs were that a higher diversity of vertebrate fauna was recorded at treatment sites and that, in the SEAP assessment, control sites received higher condition scores and lower risk scores. The differences in SEAP scores among groups were in part related to the treatment sites being drier.

It is striking that this one major baseline difference between treatment and control springs exists, considering the care taken to ensure distribution of study sites across northern Arizona and among geologic units and springs types. While these differences could be coincidental, the 4FRI planning group may have selected treatment areas they recognized as requiring specific attention. Nevertheless, if forest treatments are successful, the springs monitored in treatment areas may be more responsive than those in the control group. Thus, these baseline differences will be important to consider when interpreting the five-year sequence of monitoring data at the end of the study.

Upcoming Work

In 2020, the SSI field inventory crew will visit all 56 study sites and download flow permanence data from the Hobo Tidbit dataloggers, sample aquatic macroinvertebrates, measure springs discharge, and note changes in the size and distribution of microhabitats, as well as general habitat conditions.

While completing quality control on the baseline data, SSI staff discovered several sites with incomplete recent datasets, which will be revisited in 2020 to bring the information on them up to the level of the other sites. SSI will revisit Griffiths, Mineral, Dove, and McFarland Springs in 2020 to update information on those sites and ensure the completeness of the baseline data. Furthermore, SSI will examine and review the placement of the Hobo Tidbit devices at all sites to ensure that the data collected are the most informative. The winter of 2019-2020 was fairly normal in terms of precipitation. Because the sites in this project were visited in late summer in 2019, when groundwater flows are generally lowest, SSI intends to revisit all sites in late springtime/early summer 2020, when springs are most likely to flow. Sampling early in 2020 will permit us to begin to understand the extent of perenniality of this suite of springs.

Conclusions

In 2019 SSI completed data collection and entry on the 56 4FRI springs selected for this project. Those data serve as the baseline against which annual changes in discharge, springs area, springs invertebrates, and habitat conditions will be monitored from 2020-2022. At the conclusion of the study, all sites will be fully re-inventoried, and changes in those and additional variables will be reported. SSI will continue monitoring springs throughout this large landscape restoration effort. We look forward to continuing to collaborate with the US Forest Service and the 4FRI planning group on this important, long-term experiment in sustainable natural resource management.

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APPENDICES

Appendix A:

Springs selected as monitoring sites in the 4FRI Springs Health Monitoring Study, with date on baseline inventory, location, elevation, and lithology. Springs are organized according to treatment vs. control designation and spring type latitude-longitude coordinates are in decimal degrees, WGS 84.

Site ID	Site Name	Date	Latitude	Longitude	Elev. (m)	Primary Lithology
Treatment Sites						
Helocrene Springs						
182083	Clark Spring	10/8/2019	35.06545	-111.58367	2153	Sedimentary
776	East Twin Spring	7/29/2019	35.16906	-112.21548	2155	Igneous
430	General Springs	9/19/2019	34.45946	-111.24981	2192	Sedimentary
999	Immigrant Spring	10/13/2019	34.44087	-111.29438	2279	Sedimentary
1005	Kehl Spring	6/2/2017	34.43563	-111.31711	2268	Sedimentary
582	Lower McDermit Spring	9/19/2019	35.25786	-111.91766	2165	Igneous
1036	Middle Kehl Meadow Spring	6/23/2017	34.44512	-111.31852	2311	Sedimentary
226446	Overhang Spring	6/22/2017	34.46616	-111.3401	2199	Sedimentary
588	Rosilda Spring	7/29/2019	35.17467	-112.06092	2051	Igneous
1089	Smith Spring	9/8/2019	34.93651	-111.48593	2199	Igneous
770	Spitz Spring Lower	6/11/2018	35.26033	-111.9751	2136	Igneous
250584	Trotting Turkey Spring	10/9/2019	35.05927	-111.5898	2122	Sedimentary
1113	T-Six Spring	6/12/2018	34.90741	-111.59618	2092	Igneous
1131	Willard Spring	9/11/2019	34.97329	-111.68184	2046	Igneous
Hillslope Springs						
899	Bear Seep Tank	9/18/2019	34.94475	-111.53757	2276	Igneous
426	Bone Dry Springs	9/27/2019	34.483	-111.28047	2195	Sedimentary
162	Clover Spring West	9/18/2019	34.50588	-111.36188	2089	Sedimentary
946	Dairy Spring	9/18/2019	34.95378	-111.48177	2166	Igneous
955	Double Springs (East)	9/8/2019	34.94106	-111.49433	2206	Igneous
855	Griffiths Spring	5/29/2019	35.11724	-111.70925	2092	Igneous
989	Homestead Spring	6/24/2017	34.47081	-111.28548	2212	Sedimentary
545	Hunter Springs	9/26/2019	34.57394	-111.18902	2189	Igneous
546	Keller Spring	9/19/2019	34.48976	-111.27278	2196	Sedimentary
1011	Lauren Spring	8/5/2017	34.49158	-111.27069	2112	Sedimentary
1032	McFarland Spring	7/19/2017	34.47773	-111.19592	2235	Sedimentary
181912	North of Willard Springs	9/11/2019	34.9776	-111.6814	2062	Igneous
578	One Hundred One Spring	9/20/2019	34.48732	-111.35115	2136	Sedimentary
782	Sawmill Spring	9/25/2019	35.28865	-111.95994	2219	Igneous
Control Sites						
Helocrene Springs						
896	Banfield Spring	9/27/2019	34.65101	-111.45337	2070	Igneous
437	Coyote Spring	9/26/2019	34.44445	-111.15651	2283	Sedimentary

Site ID	Site Name	Date	Latitude	Longitude	Elev. (m)	Primary Lithology
226460	Driftfence Spring	7/19/2017	34.45502	-111.1777	2279	Sedimentary
963	Fain Spring	9/19/2019	34.81879	-111.52392	2000	Igneous
972	Foster Canyon Spring	9/20/2019	34.76072	-111.49747	1973	Igneous
1013	Lee Spring	10/1/2019	34.83571	-111.55419	2076	Igneous
1033	Meadow Spring	8/7/2017	34.42899	-111.15686	2247	Sedimentary
411	Merritt Springs	6/26/2019	34.4529	-111.18319	2274	Sedimentary
768	Mineral Spring	5/27/2014	35.25186	-111.99942	2124	Igneous
544	Monkshood Spring	9/26/2019	34.44723	-111.16472	2280	Sedimentary
425	Moonshine Spring	6/25/2019	34.47768	-111.14066	2206	Sedimentary
729	Mud Springs	7/29/2019	35.11495	-112.1868	2115	Igneous
412	Whistling Springs	6/26/2019	34.44828	-111.19014	2286	Sedimentary
1052	Wilson Spring	10/5/2019	35.33831	-111.72519	2491	Igneous
Hillslope Springs						
739	Big Spring	7/30/2019	35.15812	-112.08072	2088	Igneous
909	Bootlegger Spring	10/12/2016	34.91185	-111.53809	2257	Igneous
921	Carla Spring	7/19/2017	34.46048	-111.17152	2130	Sedimentary
951	Derrick Spring	6/26/2019	34.48902	-111.16452	2199	Sedimentary
956	Dove Spring	9/7/2016	34.8733	-111.37337	2229	Igneous
978	George Spring	6/26/2019	34.48148	-111.16695	2095	Sedimentary
982	Goshawk Spring	7/8/2017	34.43227	-111.18868	2302	Sedimentary
983	Grapevine Spring	10/2/2019	34.85841	-111.26418	2125	Igneous
1004	Jones Springs	9/20/2019	34.76321	-111.49854	1993	Igneous
1014	Leopard Frog Spring	7/7/2017	34.45205	-111.15308	2273	Sedimentary
144	Pivot Rock Spring	9/20/2019	34.49054	-111.3984	2130	Sedimentary
1075	Rock Top Spring	9/19/2019	34.85246	-111.548	1995	Igneous
226652	Spikerush Spring	7/8/2017	34.4236	-111.19143	2321	Sedimentary
1096	Strahan Spring	10/3/2019	35.08205	-111.92416	1947	Igneous

Appendix B:

Hobo Tidbit installation locations and flow measurement locations for each of the 56 springs selected as monitoring sites in the 4FRI Springs Health Monitoring Study (attached as an Adobe pdf document).

Appendix C:

Baseline data summary inventory reports for each of the 56 springs selected as monitoring sites in the 4FRI Springs Health Monitoring Study (attached as an Adobe pdf document).