SPRING HEALTH MONITORING FOR THE 4 FOREST RESTORATION INITIATIVE
2020 ANNUAL PROGRESS REPORT
USFS Cost Share Agreement #19-CS-11030400-015

Hobo Tidbit datalogger installation at Clark Spring, Coconino National Forest.

Report prepared by:
Museum of Northern Arizona Springs Stewardship Institute
3101 N. Ft. Valley Rd. Flagstaff, AZ 86001
(928) 774-5211 x 231
SpringStewardshipInstitute.org

Submitted to:
Coconino National Forest
1824 S. Thompson St.
Flagstaff AZ, 86001
and
Kaibab National Forest
800 S. 6th Street
Williams, AZ 86046

30 MARCH 2021

THIS PAGE INTENTIONALLY LEFT BLANK

Contents

List of Figures

List of Tables

ACKNOWLEDGEMENTS

We thank Mr. John Souther of the Coconino National Forest for his administrative support of this project. We thank Mr. Ed Schenk for his project advisement and assistance. We thank the Museum of Northern Arizona for administrative support and curation of specimens. Field and laboratory data collection and report preparation were accomplished through the concerted efforts of the MNA Springs Stewardship Institute staff, including Larry Stevens, Jeri Ledbetter, Andrea Hazelton, Jeff Jenness, Alek Mendoza, Brianna Mann, and Brandon Ragan. We warmly thank Gloria Hardwick and Jeff Averitt for field and taxonomic assistance and their enthusiastic support of this project.

RECOMMENDED CITATION

Springs Stewardship Institute. 2021. Spring Health Monitoring for the Four Forest Restoration Initiative 2020 Annual Progress Report. Prepared for the Coconino and Kaibab National Forests. Museum of Northern Arizona, Flagstaff.

THIS PAGE INTENTIONALLY LEFT BLANK

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 documents and compares 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 second year of this five-year monitoring program. The data presented here build on the 2019 baseline data 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 of the Monitoring Study Design

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 years one and two.

In year one of the study (2019) SSI staff completed study site selection according to a stratified design (see Fig. 1, Table 1, and Appendix A) and conducted initial visits at 56 springs located across the Kaibab and Coconino National Forests. At each site, the field crews produced a baseline dataset for this monitoring study by completing a Level 2 spring inventory (or reviewing , installing a HOBO Tidbit data logger device for yearly water level assessment. SSI staff updated the Springs Online Database (*http://springsdata.org/*) with the new data from the above inventories and conducted quality control checks on all data entered. Results of this 2019 work were submitted to the US Forest Service in an annual report in April of 2020.

In 2020, SSI staff continued the monitoring study by completing the following tasks, as outlined in the scope of work, at all 56 study springs. Because of the Coronavirus Pandemic it was not feasible to engage volunteers as planned, so SSI staff and contractor Ed Schenk completed all field work.

1. Download hydrologic data from HOBO Tidbit dataloggers.

2. Measure springs discharge and document habitat area change and springs invertebrate assemblages.

3. Conduct quality control checks on data from springs and thermistors, and upload data to Springs Online or other agreed upon databases.

4. Collect additional data as necessary to complete the baseline dataset with high quality data (this task, while not specifically mentioned in the scope of work, is crucial for study outcomes.

During years three and four of this monitoring program, SSI staff will coordinate volunteers (to the extent possible) 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.

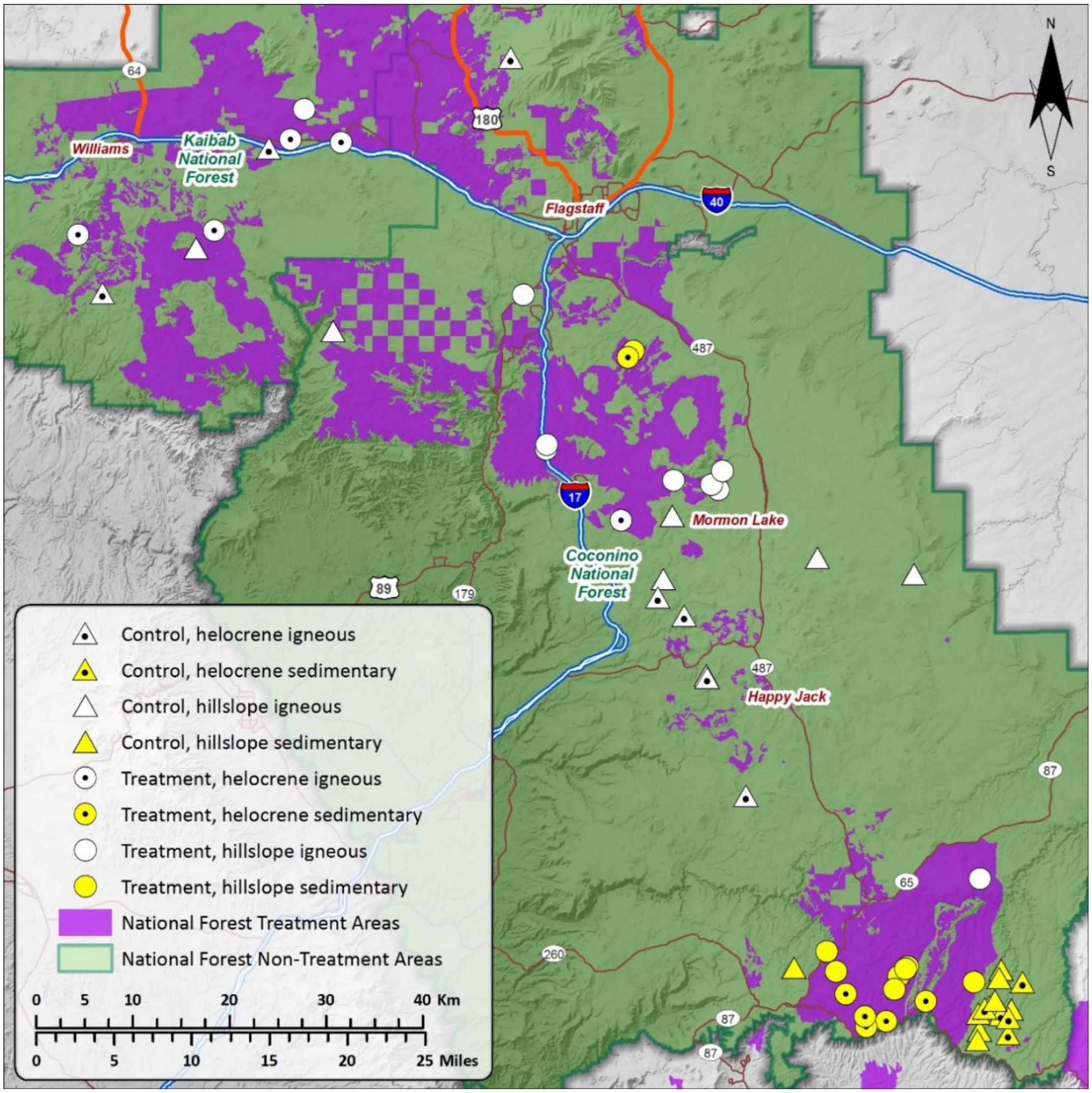

Figure 1. Map showing the 56 study sites in the 4FRI Spring Health Monitoring Study. The list of monitoring sites, with geographic coordinates and elevations, is included as Appendix A.

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. See the 2019 annual report for more details about site selection.

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**

Year 2 (2020) Tasks

Task 1: Download hydrologic data from HOBO Tidbit dataloggers

SSI field crews visited each of the 56 study springs, searched for the HOBO Tidbit Datalogger, and if found, downloaded the data. Field staff made detailed notes about where the device was located when found in 2020 and whether it appeared to have been disturbed during the year. They also noted whether it was necessary to disturb the device to download the data (the devices cannot transmit data when submerged under water) and documented the precise configuration of the device after reinstallation. Crews recorded the absolute water depth where the device was installed, and whether it was installed in standing or flowing water.

In some cases, the survey crew was not able to find the dataloggers. In these cases, they installed a new datalogger and properly documented the installation location.

Task 2: Measure springs discharge and document habitat area change and springs invertebrate assemblages

Springs Discharge Rate: Survey crews measured the springs discharge rate at all sites where there was flowing water. Flow measurement techniques were selected according to the amount of flow and site geomorphology. At all springs but one, the timed flow capture (volumetric) technique was used. In the remaining spring (Double East Spring), the crew used a flume to measure flow. Crews documented the flow measurement location by describing it on the data sheet and marking it on the sketchmap.

Habitat Change: Crews documented changes in habitat areas by using a red pencil to draw edits on the site sketchmap from the original baseline dataset. Site sketchmaps are drawn to scale, and include the configuration and area of microhabitats at the springs ecosystem, such as pools, channels, stream banks, wet backwalls, and cienegas (wet meadows). The sketchmap edits were used to estimate any changes in the areas of microhabitats. Surveyors also documented the water depth, percent inundation, and soil moisture status of each microhabitat, to allow comparison in moisture levels from year to year.

Invertebrate Assemblages: Opportunistic sampling of benthic macroinvertebrates (BMI) was conducted at the study springs using dip- and kick-net sampling, aerial net sweeping of shoreline vegetation, and examination of firm strata in subaqueous and shoreline habitats. Specimens, when collected, were placed in 80% EtOH and transferred to the MNA Merkel Laboratory for sorting, preparation, and identification.

Quantitative BMI sampling was conducted at sites with sufficient discharge to permit use of a dip- or kick-net to sample the springbrook channel. Quantitative BMI sampling was conducted in springtime and summer 2020 using a timed kicknet method. A 1.0 mm-mesh kicknet was placed on the channel floor at the source and at two locations downstream, and a 0.093 m2 area immediately upstream from the net was vigorously disturbed for one minute. Macroinvertebrates in the net were counted and released back into the stream, except for several voucher specimens of each species, which were collected in 80% EtOH for identification purposes. Voucher specimens were returned to the MNA Merkel Zoology Laboratory for sorting, preparation, and identification. Velocity, depth, and field water quality variables (temperature, pH, dissolved oxygen concentration, and conductance) were measured at each site, and substrate composition was recorded at each sample.

Task 3: Conduct quality control checks on data and upload to Springs Online or other agreed upon database

SSI staff updated the Springs Online database with the new data from all 2020 field inventories and conducted quality control checks on all data entered. The paper field sheets are archived in the SSI labs at the Museum of Northern Arizona, and electronic scans of the field sheets are archived on the SSI server. Hydrologist Ed Schenk conducted quality control checks on the data downloaded from the Hobo dataloggers, and completed preliminary analyses. SSI staff archived the downloaded Hobo data on the SSI server. Eventually all Hobo data will be uploaded onto Springs Online or other agreed-upon database.

Task 4: Collect additional data as necessary to complete the baseline dataset with high quality data (not in the scope of work).

Data quality control in 2019 revealed that several of the baseline (year 1) datasets were incomplete, or contained data that would not have been of adequate quality to support the final analysis in year 5. This was primarily related to our partial reliance on using some surveys which were completed prior to 2019, sometimes by volunteers lacking technical knowledge. The most common parts of the baseline survey that needed to be repeated in 2020 were the botany survey, delineating microhabitats, describing the substrate particle size distribution, and drawing the sketchmap.

SSI field crews completed a botany survey for 10 springs in 2020 (Table 2), and in most of these cases also re-delineated microhabitats and drew a new sketchmap as well. Crews drew new sketchmaps of thirteen additional springs (Table 2). The decision was made to draw a new sketchmap when the survey crew discovered that the original sketchmap associated with the baseline survey had not been drawn to scale with adequate detail. One important component of this monitoring study is tracking microhabitat changes, and this is only possible with a detailed, properly scaled baseline map. These new sketchmaps, microhabitat, botany, and substrate data will be added to the baseline dataset for the trends analysis in year 5.

Table 2. Springs for which 2020 survey crews gathered additional data to complete the baseline survey for this monitoring study. For springs listed as receiving a 2020 botany survey, crews generally also drew a new sketchmap and described substrate particle size distribution.

Site ID	Spring Name
New Botany Survey	
899	Bear Seep Tank
956	Dove Spring
855	Griffiths Spring
1005	Kehl Spring
1033	Meadow Spring
1036	Middle Kehl Meadow Spring
768	Mineral Spring
544	Monkshood Spring
181912	North of Willard Spring
1131	Willard Spring
New Sketchmap Only	
921	Carla Spring
437	Coyote Spring
946	Dairy Spring
982	Goshawk Spring
989	Homestead Spring
1013	Lee Spring
1032	McFarland Spring
411	Merritt Spring
425	Moonshine Spring
729	Mud Spring
226652	Spikerush Spring
412	Whistling Spring
1052	Wilson Spring

RESULTS

Task 1 (2020): Download hydrologic data from HOBO Tidbit dataloggers

Completeness of the dataset

Of the 56 Hobo Tidbit dataloggers installed at monitoring sites in 2019, survey crews successfully located and downloaded data from 50 of them. In one case (Mineral Spring), the surveyors were able to download the data via the remote Bluetooth connection despite not being able to physically locate the device. In most cases, surveyors do not know what happened to the devices; they were simply missing (Table 3). There were two incidents of wildlife chewing on the devices, though in one of those cases it was still possible to download the data.

Table 3. Springs monitoring sites where it was not possible to locate the Hobo Tidbit or download a full set of data.

Spring Name	**Status of Hobo Tidbit dataloggers**
East Twin Spring	Installed in a dry pond (2019). Pond was full of water in 5/2020 and surveyors could not find the datalogger. Surveyors planned to return in late summer when water level might be lower, but USFS closed the access road.
George Spring	Destroyed by rodents. New device installed 5/5/20.
Griffiths Spring	Successful download 6/5/20. Missing when surveyors returned for botany survey 8/25/20; new device installed 9/12/20.
McFarland Spring	Not found. New device installed 5/16/20.
Mineral Spring	Not found, though it was possibly to download the data via Bluetooth on 5/5/20. Could not access via Bluetooth connection on 6/25/20, so surveyors installed a new datalogger.
Spikerush Spring	Not found, though the PVC pipe it had been attached to was found. New datalogger installed 5/15/20.
Willard Spring	Not found. New device installed 4/19/20.

Preliminary Analysis of hydrologic data from Hobo Tidbits

Because only one year of monitoring data is available at this time, we present a preliminary analysis which focuses on comparing the hydrologic conditions at hillslope springs with the conditions at helocrene springs. The summary table of hydrologic data used for the following analyses and figures is attached as Appendix B.

Water Depth: Absolute water depth adjacent to the installed Hobo was greater at helocrenic springs, but the difference was not statistically significant (ANOVA single factor, p = 0.88; Fig. 2).

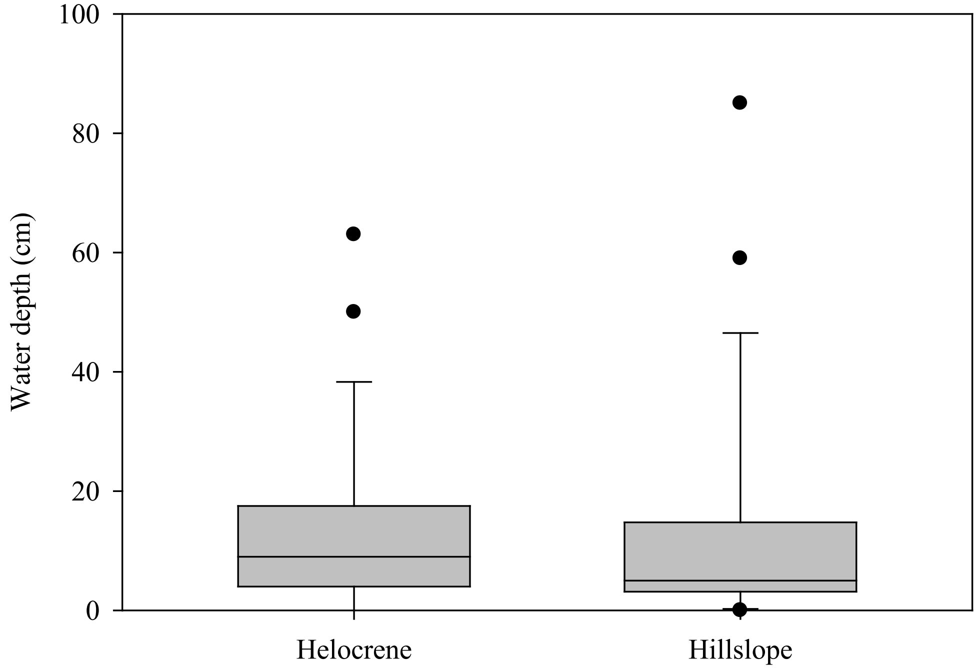

Figure 2. Water depth at Hobo Tidbit location, by springs type. Helocrene sites were slightly deeper but not statistically significant.

Inundation Time: The percent of time that each Hobo Tidbit was submerged was evaluated for the period of record (Fig. 3). In general, this spanned from summer 2019, the initial installation, until summer 2020, the first year of monitoring. The percent time inundated will be used to determine climate and 4FRI treatment impacts on springs flow. The inundation period for this first year should not be interpreted for any trends or correlation since the location of the Hobo Tidbit water sensor was chosen to be at the fringe of springs flow. The location is arbitrary and does not record absolute springs perenniality.

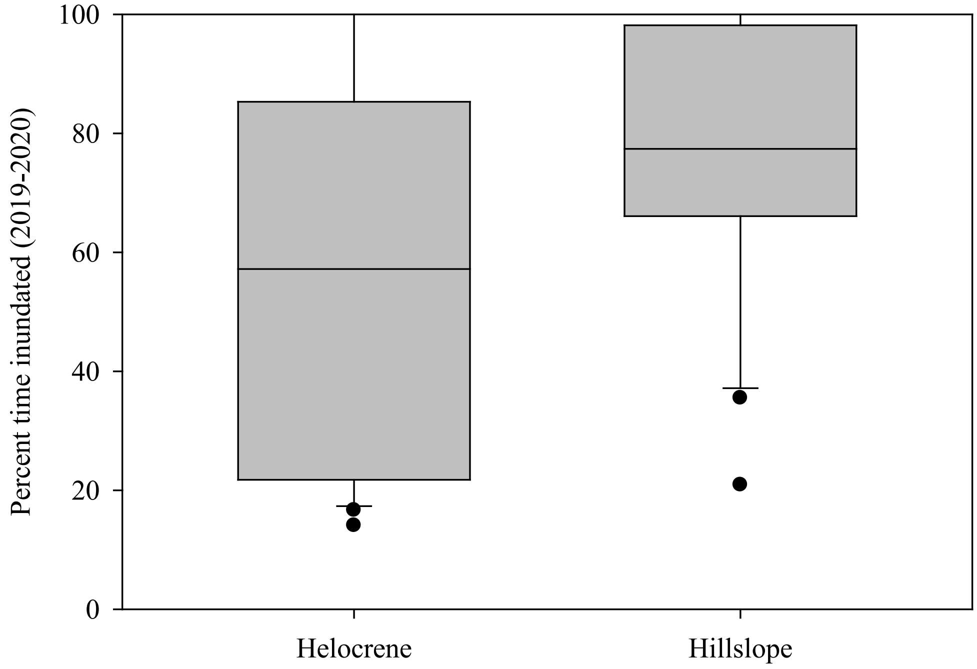

Figure 3. Period of time the Hobo Tidbit was inundated by springs type. For the first year this information is purely baseline data and should not be interpreted.

Springs Temperature Response: A continuous record of water temperature can provide a measure of springs responsiveness to surface activities (Figs. 4, 5, and 6). Similar studies at the Grand Canyon using water temperature were able to determine the response time of Roaring Springs to rain and snow events (e.g., Schindel 2015; Jones et al. 2017). Monitoring the springs response rate will help interpret future results from this study.

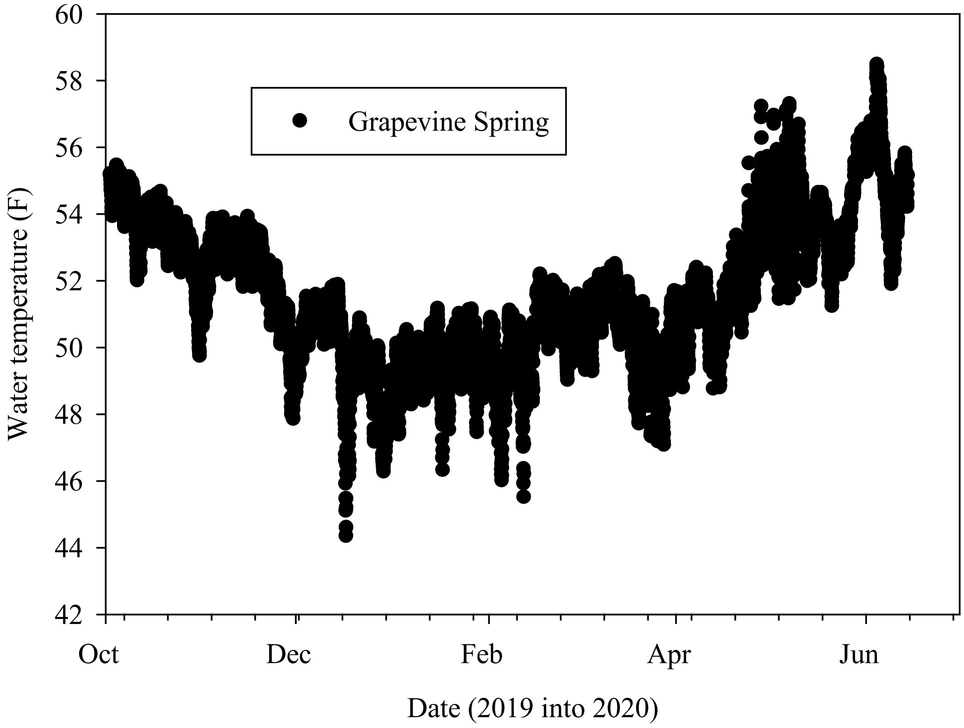

Figure 4. Springs water temperature for a hillslope spring with a fast groundwater response time. The water temperature changes are rapidly driven likely both by groundwater recharge (high groundwater response) and air temperature (surface response). Further data, including modeled precipitation data, will elucidate a better response interpretation.

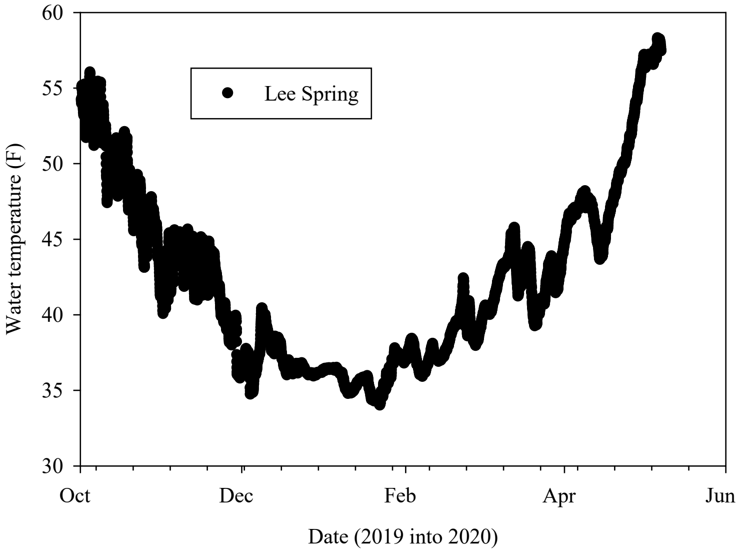

Figure 5. Springs water temperature for a helocrene spring with a low discharge rate. Water temperature is driven by mean air temperature, the groundwater response time cannot be determined due to the water temperature being controlled by air temperature.

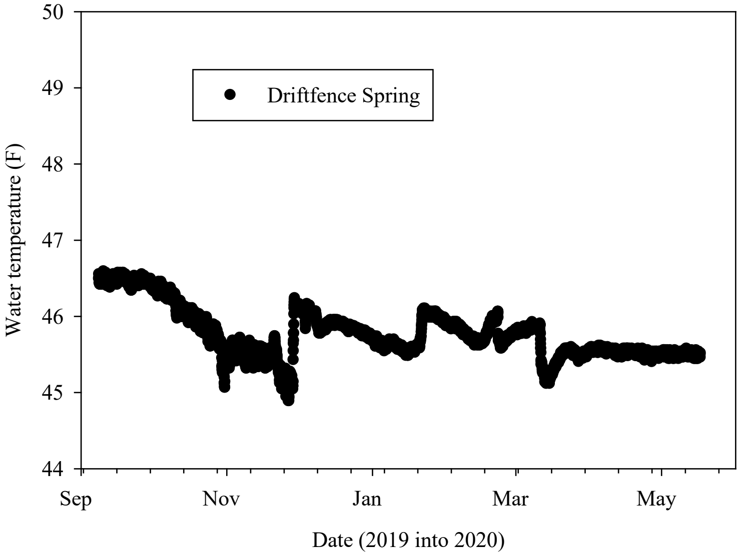

Figure 6. Springs water temperature for a less responsive spring (note y-axis scale). This spring is complacent in regard to both groundwater response and air temperature, indicating good springs flow from a relatively old source.

Task 2: Measure springs discharge and document habitat area change and springs invertebrate assemblages

Springs Discharge Rate

Hillslope springs had greater flow than helocrenic springs (ANOVA single factor, p = 0.04), as measured during the 2020 site visits when the Hobo Tidbits were downloaded (Fig. 7). Mean springs discharge rate at hillslope springs was 2.2 L/s, while the mean discharge rate at helocrene springs was 0.4 L/s.

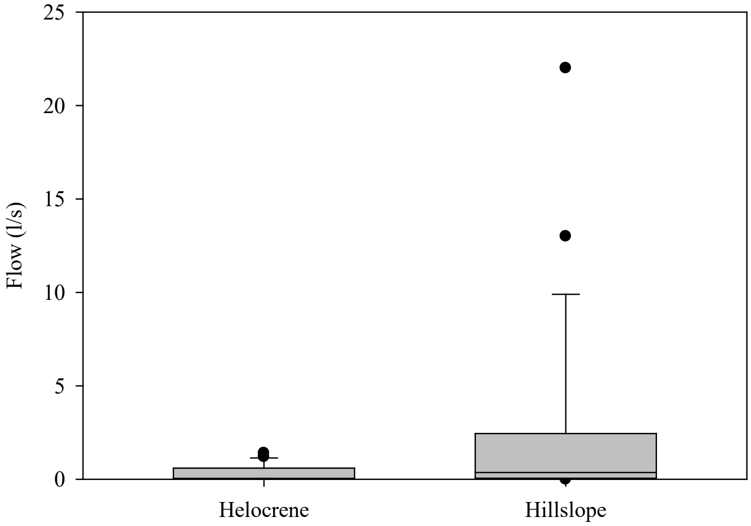

Figure 7. Springs discharge rate as measured in 2020, by springs type.

Habitat Change

SSI survey crews documented changes in microhabitat areas at 15 of the 56 springs (Table 4). In almost all cases these changes were related to wetter conditions during the 2020 survey, compared to baseline conditions. Most of the 2020 surveys were completed in late spring, when flow rates were elevated following the winter season. In contrast, the 2019 baseline surveys were conducted in late summer and early autumn, and at that time conditions were exceptionally dry because the region received almost no monsoon activity in 2019.

Recall that some of the baseline surveys were conducted prior to 2019, but SSI surveyors decided to re-draw the sketchmaps for many of those surveys in 2020. In those cases, it was not possible to detect microhabitat area changes with any accuracy, and instead the new 2020 maps will be used as the baseline.

Table 4. Description and explanation of changes in microhabitat areas between the baseline survey map and 2020. Changes were documented at 15 of 56 springs.

Site ID	Site Name	Microhabitat Area Changes
739	Big	Source channel expanded by 11 m^2 due to wetter conditions. This area was subtracted from the colluvial slope that surrounds the source.
162	Clover West	Channel increased by 9 m^2 due to higher flow rate. Channel margin decreased by 3 m^2 due to being subsumed into channel.
956	Dove	Pool increased by 9 m^2 due to wetter conditions. Pool margin decreased by 9m^2 due to pool expansion.
226460	Driftfence	4m^2 shifted from source to channel. It's possible the channel has become more incised through the source area, or flow is greater, making that 4m^2 appear more channel-like. 210 m^2 shifted from terrace to low gradient cienega due to wetter conditions.
776	East Twin	Pool decreased by 26 m^2. It was dry when originally mapped in 2019; in 2020 surveyors reduced pool size to only the area that contained water during the survey. Pool perimeter increased by 12m^2 due to pool size decrease. Uphill low gradient cienega increased by 28 m^2 and downhill low gradient cienega increased by 161 m^2 due to wetter conditions.
963	Fain	17m^2 shifted from low gradient cienega to pool due to wetter conditions.
972	Foster Canyon	Low gradient cienega increased by 17 m^2 due to wetter conditions.
181912	North of Willard	A new map was drawn in April 2020. In Aug 2020, a surveyor decreased the low gradient cienega by 23 m^2 due to dryer conditions in late summer compared to spring.
1075	Rock Top	The source cienega decreased by 7 m^2. This was related to the source shifting to is slightly different location.
588	Rosilda	Pool increased by 113 m^2 due to wetter conditions. Pool margin decreased by 55 m^2 due to expansion of pool.
782	Sawmill	The lower low gradient cienega shrank by 1 m^2.
770	Spitz lower	The channel decreased by 8 m2, but surveyors added a 161 m^2 low gradient cienega to reflect dramatically wetter conditions.
1096	Strahan	Channel increased by 1 m^2 and terrace decreased by 1 m^2. Despite the small area of the changes, there was shifting of several microhabitat boundaries (see sketchmap).
1113	T-Six	Due to wetter conditions and likely also geomorphic recovery following restoration in 2018, the boundary of this site expanded, increasing the source channel by 80 m^2 and increasing the low gradient cienega by 3,334 m^2. The downstream channel was subsumed into the two previously mentioned microhabitats, as it could no longer be distinguished.
1052	Wilson	Due to much wetter conditions, the pool increased by 44 m^2 and the channel increased by 46 m^2. The channel margin decreased by 40 m^2 due to the expansion of the channel.

Invertebrate Assemblages

Overview: Taxonomic identifications are on-going. However, several generalizations about assemblage composition among treatments and with regard to differences among springs can be made at this time.

Assemblage Composition: We detected a total of 5804 BMI among at least 75 aquatic and riparian invertebrate taxa, including representatives among 54 families in 26 orders (Fig. 8). The overall composition of invertebrates detected in or on the riparian wetted edges of the springs is dominated by several groups with the following relationship (Fig. 8):

Diptera > Trichoptera = Coleoptera > Ephemeroptera > Plecoptera > Turbellaria > Microcrustaceans > Oligochaetae = Hemiptera > Bivalvia = Ixodes > Gastropoda > Amphipoda > Nematoda > Other

The overall springs assemblage is dominated by Diptera, with Chironomidae the most abundant, followed by Sepsidae and many other true fly taxa. Within this diverse macroinvertebrate assemblage are several taxa often recognized as indicators of ecological integrity, including the native amphipod Hyalella azteca, dryopoid beetles (e.g., Elmidae), as well as Ephemeroptera mayflies, Plecoptera stoneflies, and Trichoptera caddisflies (Fig. 8). The latter three orders (abbreviated as "EPT") are widely used as indicators of high water quality. However, only some individual EPT taxa serve as water quality indicators, while others can be tolerant of lower water quality.

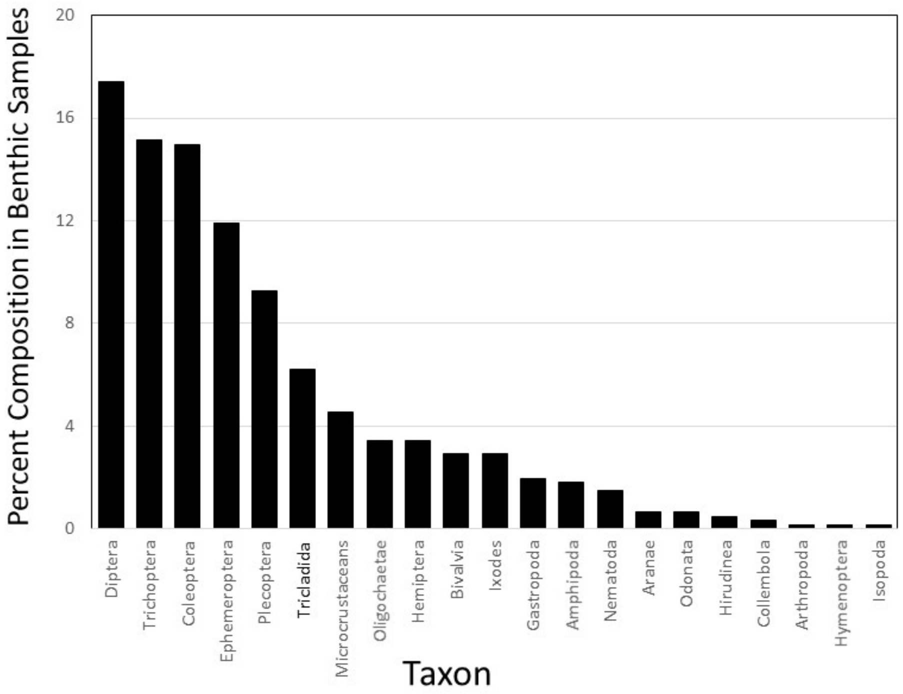

Figure 8. Percent composition of benthic macroinvertebrates in quantitative samples, ordered by abundance.

At present, differences among spring types, aquifer (rock) types, and forest treatments are complex to interpret (Fig. 9). Abundance varies substantially among taxa and spring, rock, and treatment types, necessitating log-transformation to reduce variance. Some taxa only have been detected in lentic, helocrenic habitats (e.g., Ostracoda), while others are largely restricted to lotic hillslope springs (e.g., Plecoptera), and others are more catholic in their distribution (e.g., Ephemeroptera, Chironomidae). The array of species varied between the two springs types (wet meadow helocrene springs vs. hillslope springs), between the two rock types (igneous and sedimentary), and the proposed treatments. The most stenotolerant taxa (e.g., several Plecoptera, Elmidae beetles, perhaps Enochrus water scavenger beetles) are patchily distributed, but generally occur in the least altered habitats. However, it is not fair to assume that the absence of these taxa in various settings is attributable to population loss due to anthropogenic stewardship. Much variation exists among closely adjacent springs, in large part due to the vagaries of colonization and the high level of ecosystem individuality that characterizes many springs, and which may have naturally excluded those species. More resolution on habitat affinity among taxa in spring, rock, and treatment types will emerge as taxonomy is refined.

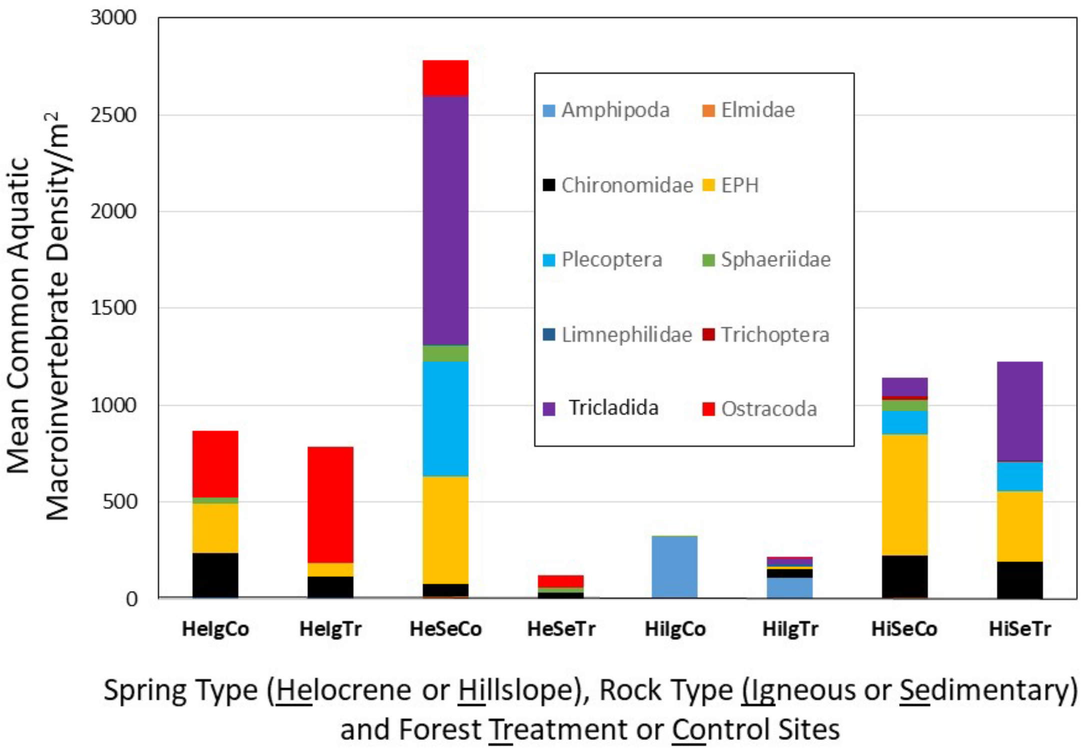

Figure 9. Mean density (no. indivs/ m^2) of common aquatic macroinvertebrates among spring types, parent bedrock types, and forest treatments.

Substrate composition is a strong determinant of BMI composition and density (Stevens et al. 2020; Fig. 10). Mixed gravels and cobbles channel floors tend to support more complex BMI assemblages, while fine sediment benthos can support high densities of Ostracoda and other BMI. Organics-dominated substrata support Chironomus bloodworms, Annelida, and other ooze-dwelling taxa.

Velocity is an important factor in BMI composition. Velocity varied from 0 to 1.2 m/s among the stations sampled at the springs visited that had sufficient flowing water for measurement and quantified BMI analyses (Fig. 11). Springbrook velocity strongly influences the composition of channel floor materials, and consequently the habitat available for benthic macroinvertebrates. All taxa detected in this study except Chironomidae midges were strongly asymptotically distributed in relation to velocity. Fig. 11 is an example of the asymptotic distribution of Tricladida flatworm density/m2, with highest values at lowest velocity and lowest density at highest velocities. However, this asymptotic velocity relationship is in part a function of the shallow depths of most springs in the study, with only a few cm of water depth at most sites. Velocity and overall discharge were not strongly related to total springs-influenced habitat area, due in many cases to the source(s) emerging onto steeply sloping bedrock or boulders, conditions that constrain the area of the wetted perimeter.

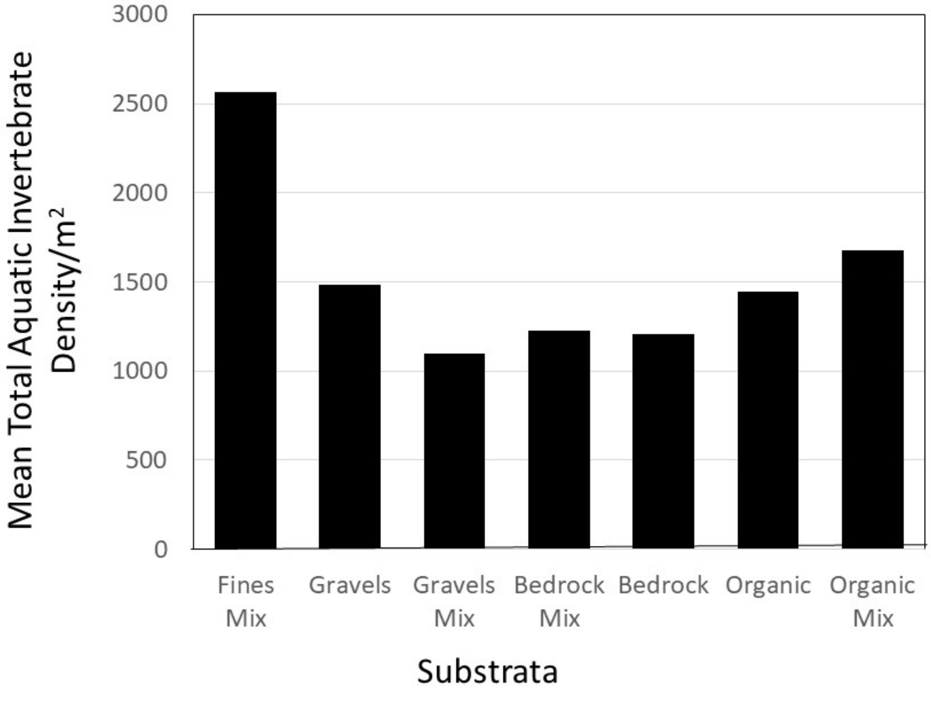

Figure 10. Mean total aquatic macroinvertebrate density(no. indivs/ m^2) in relation to channel floor substrata.

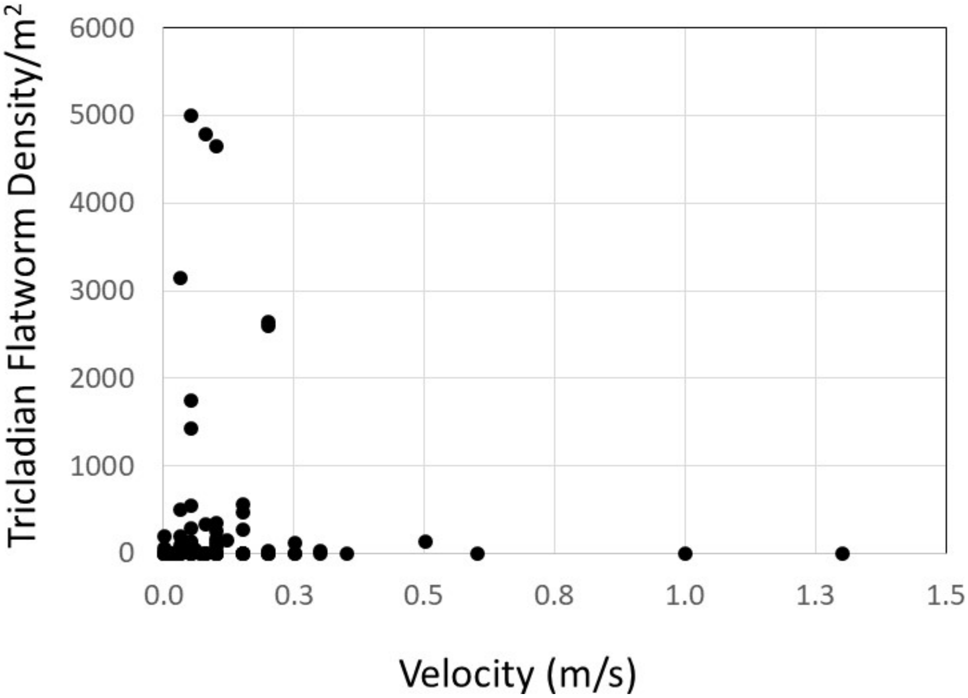

Figure 11. Asymptotic distribution of flatworm density (no. indivs/ m^2) in relation to stream velocity (m/s).

Although still preliminary, Plecoptera stonefly density may be a promising invertebrate indicator of habitat quality among these treated and untreated 4FRI springs. Stoneflies are generally coolwater species that are highly intolerant of degraded water quality and habitat conditions. Several stonefly species are present in some of the springs, including the large, predatory Hesperoperla pacifica. Stonefly densities ranged from 0 to 2,767 individuals/m2. Log10 transformation of Plecoptera density/m2 was strongly related to the assessed condition of site geomorphology, which includes the ecological integrity of habitat configuration, springbrook channel geometry, soil integrity, geomorphic diversity (measured as the Shannon-Weiner H' value based on proportional contribution of associated microhabitats), and disturbance intensity. With SEAP assessment geomorphic condition scores categorized from 0 (obliterated) to 6 (pristine), Plecoptera density increased markedly with each increment of geomorphic integrity above a score of 2 (strongly degraded), reaching an average maximum of 107 individuals/m2 under near pristine conditions (Fig. 12). We will present EPT scores for each sample in the next report; however, the affinity of many Ephemeroptera mayflies to occupy degraded, lentic waters is likely to result in reduced correlation between those taxa as indicators with habitat assessment scores (Fig. 13).The invertebrate data used for these analyses are attached in Appendix D.

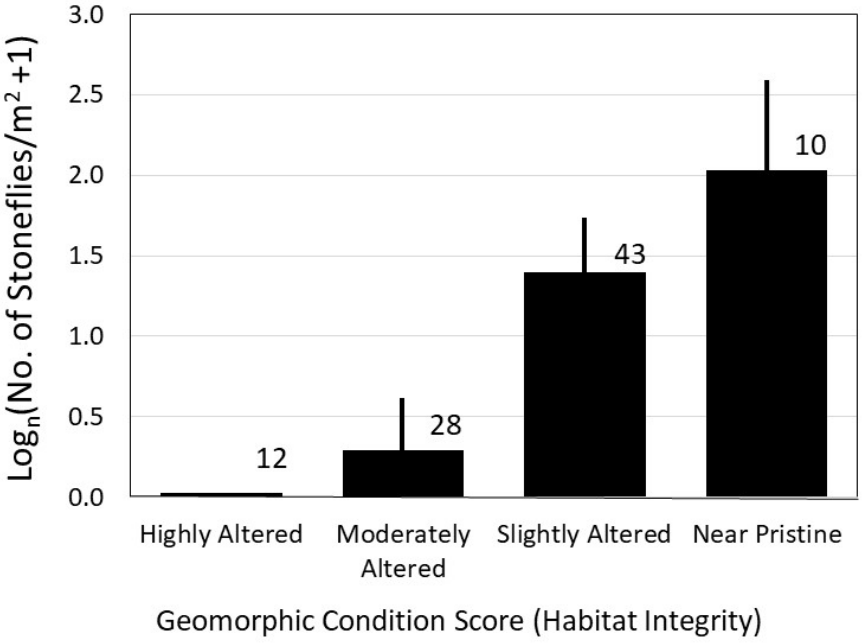

Figure 12. Log$_{10}$-transformed stonefly density (no. indivs/m^2) in relation to geomorphic habitat condition scores in the 4FRI study area, showing high affinity of Plecoptera for ecologically intact springs. Error bars are 95% confidence intervals.

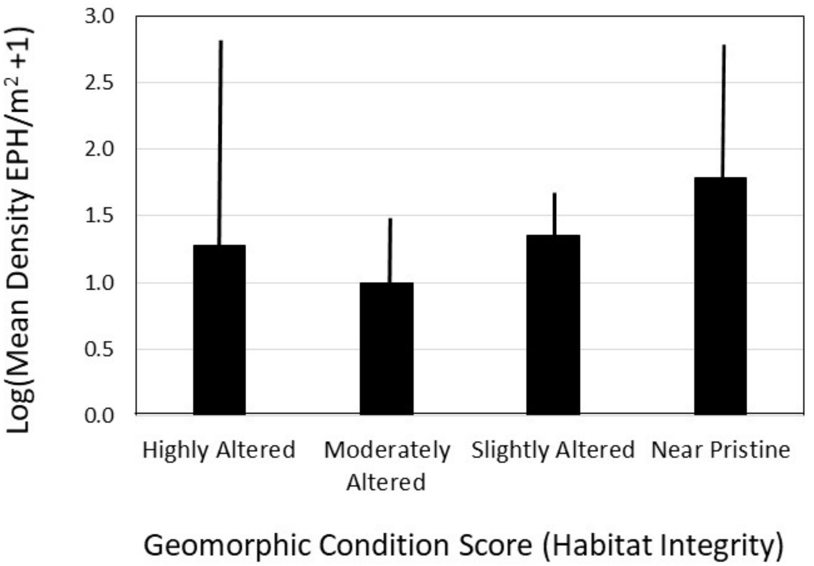

Figure 13. Log$_{10}$-transformed mayfly density(no. indivs/m^2) in relation to geomorphic habitat condition scores in the 4FRI study area, showing low affinity of Ephemeroptera for ecologically intact springs. Error bars are 95% confidence intervals.

Task 3: Conduct quality control checks on data and upload to Springs Online or other agreed upon database

All 2020 field data is in Springs Online and has been quality-checked. Survey summary reports, which were exported from Springs Online and summarize the data collected at each spring in 2020, are attached as Appendix C.

The data downloaded from the Hobo Tidbits are currently archived on the SSI serve at the Museum of Northern Arizona, and are also saved on at least one other computer. At the end of this five-year study, the complete dataset will be archived in a location to be determined, which will be agreed upon in discussions with the US Forest Service.

DISCUSSION

Hydrology

The hydrologic analysis examined the first year of data downloaded from the Hobo Tidbit dataloggers, and compared hydrologic characteristics between hillslope springs and helocrene springs. Hillslope springs are springs with one or more discrete sources flowing from a hillside, usually down a channel. Helocrene springs are wet meadows, characterized by diffuse flow throughout an often large open clearing. While helocrene springs can have channels passing through them, it is more characteristic for this springs type to have standing water or sluggishly flowing water. The preliminary analysis of the year 1 hydrologic data supports these springs type descriptions, with helocrene springs having lower discharge rates and slightly deeper water than the hillslope springs.

Habitat Change

The most striking differences noted in the springs habitat between the baseline dataset and 2020 were related to the wetter conditions in 2020. Many ponds and cienegas that were recorded as dry in the baseline dataset had standing water or discernible springs flow in 2020. The final analysis of habitat change in year 5 will incorporate the climate record and the hydrologic data being collected by the Hobo Tidbits and annual flow measurements, in order to better understand how these variables are connected.

Invertebrate Assemblages

Preliminary examination of the BMI data reveals great variation among species and spring types, aquifer rock types, and forest treatment factors. Chironomidae are the most ubiquitous taxa, occurring at nearly every site; however, the many species in the chironomid assemblage likely play a wide number of ecological roles and have greatly varying tolerance levels. While Ephemeroptera (Fig. 13) and some Trichoptera are fairly widespread, these species exhibit a wider array of tolerance to anthropogenic disturbances. In contrast, Plecoptera appear to be the most sensitive indicators of high quality habitat, but primarily occur in lotic habitats (Fig. 12), and therefore may not be expected at all springs. Their habitat specificity may limit their utility in landscape treatment assessment.

We are progressing with analysis of invertebrate assemblage differences between aquifer types, forest treatment types, and in relation to water quality variables. Quantitative aquatic macroinvertebrate samples have been collected, sorted, and preserved. Taxonomic analyses are still underway, but will be sufficiently complete in Year 3 of the study to permit testing with multivariate analyses, such as principal components analysis or non-metric multidimensional scaling. Such statistical tests often are used to describe variation in distributional patterns among taxa that serve as indicators of quality habitat and to reveal relationships between physical variables and BMI assemblage composition and structure.

Upcoming Work

In 2021, the SSI field inventory crew will re-visit all 56 study sites and download flow permanence data from the Hobo Tidbit dataloggers, measure springs discharge rate, and note changes in the size and distribution of microhabitats, as well as general habitat conditions. We will continue to analyze benthic macroinvertebrate data to better understand which taxa may best serve as indicators of environmental factors, including water quality, aquifer (rock) type, springs typology, and Forest treatments.

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 through 2022. In 2020, SSI completed hydrologic monitoring, recorded springs habitat changes, completed invertebrate sampling at each study spring, and supplemented the baseline dataset with carefully drawn sketchmaps and new botany surveys. 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.

REFERENCES CITED

Schenk, E.R., L.E. Stevens, J.S. Jenness, and J. Ledbetter. 2019. Groundwater Yield and Springs Monitoring Plan in Forest Thinning Treatments of the Four Forest Restoration Initiative (4FRI). Springs Stewardship Institute Technical Report, Flagstaff, AZ. 51 pp.

Stevens, L.E., A.E. Springer, and J.D. Ledbetter. 2016. Springs Ecosystem Inventory Protocols. Springs Stewardship Institute, Museum of Northern Arizona, Flagstaff, Arizona. Available online at http://docs.springstewardship.org/PDF/ProtocolsBook.pdf.

Stevens, L.E., J.H. Holway, and C. Ellsworth. 2020. Benthic discontinuity between an unregulated tributary and the dam-controlled Colorado River, Grand Canyon, Arizona, USA. Annals of Ecology and Environmental Science 4:33-48. ISSN 2637-5338.

APPENDICES

Appendix A. Springs selected as monitoring sites in the 4FRI Springs Health Monitoring Study

Includes the date of the 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; Appendix A is included at the end of this document.

Appendix B. Summary of hydrologic data from the Hobo Tidbit dataloggers.

Includes absolute water depth in 2020 where the Hobo is installed, the status of the spring flow at the Hobo in 2020, the percent of time that the Hobo was inundated, and the measured spring flow rate in 2020. Appendix B is included at the end of this document.

Appendix C. Summary reports describing results of all 2020 field surveys

Download from *http://docs.springstewardship.org/Reports/4FRI_2020.zip*

Appendix D. Benthic macroinvertebrate data

Due to the width of the worksheet, these data are submitted electronically in Microsoft Excel format. The file is included in the same .zip file as Appendix C and can be downloaded from *http://docs.springstewardship.org/Reports/4FRI_2020.zip*.

APPENDIX A

Springs selected as monitoring sites in the 4FRI Springs Health Monitoring Study, with date of 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	Spring 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

Site ID	Spring Name	Date	Latitude	Longitude	Elev. (m)	Primary Lithology
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
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

Summary of hydrologic data from the Hobo Tidbit dataloggers, including absolute water depth in 2020 where the Hobo is installed, the status of the spring flow at the Hobo in 2020, the percent of time that the Hobo was inundated, and the measured spring flow rate in 2020. Springs are organized according to springs type, with helocrene springs listed first, followed by hillslope springs.

Site ID	Spring Name	Absolute Water Depth (cm) at Hobo, 2020	Standing, Flowing, or Dry at Hobo, 2020	Measured Spring Flow Rate (L/s), 2020	Time Inundated (%)
Helocrene Springs					
896	Banfield Spring	0	dry	0.07	32
182083	Clark Spring	20	standing	0.00	52
437	Coyote Spring	9	flowing	0.59	82
226460	Driftfence Spring	4	standing	0.61	100
776	East Twin Spring	--	-------	-----	----
963	Fain Spring	19	standing	0.25	95
972	Foster Canyon Spring	14	standing	0.47	----
430	General Spring	50	flowing	0.48	77
999	Immigrant Spring	0	dry	0.00	22
1005	Kehl Spring	0	dry	0.97	59
1013	Lee Spring	10	standing	0.00	100
582	Lower McDermitt Spring	0	dry	0.00	18
1033	Meadow Spring	4.4	flowing	0.04	51
411	Merritt Spring	5	flowing	0.29	21
1036	Middle Kehl Spring	12	flowing	1.10	20
768	Mineral Spring	4	flowing	0.04	17
544	Monkshood Spring	4	flowing	0.046	48
425	Moonshine Spring	19	standing	1.20	14
729	Mud Spring	63	standing	0.00	72
226446	Overhang Spring	16	flowing	0.80	64
588	Rosalida Spring	15	standing	0.00	71
1089	Smith Spring	30.5	flowing	1.40	100
770	Spitz Spring	9.4	standing	0.02	36
250584	Trotting Turkey Spring	5	standing	0.00	22
1113	T-Six Spring	4	standing	0.00	74
412	Whistling Spring	4.5	flowing	0.12	55
1131	Willard Spring	9	flowing	0.04	100
1052	Wilson	15	flowing	3.1	----
Hillslope Springs					
899	Bear Seep Tank	85	standing	0.00	36
739	Big Spring	3.5	flowing	2.69	59
426	Bone Dry Spring	0	dry	0.00	67
909	Bootlegger Spring	0.5	flowing	0.04	68

Site ID	Spring Name	Absolute Water Depth (cm) at Hobo, 2020	Standing, Flowing, or Dry at Hobo, 2020	Measured Spring Flow Rate (L/s), 2020	Time Inundated (%)
921	Carla Spring	3	flowing	0.51	78
162	Clover West Spring	15	flowing	6.79	77
946	Dairy Spring	24.8	flowing	22.00	100
951	Derrick Spring	6	flowing	1.70	88
955	Double (East) Spring	34	flowing	4.50	100
956	Dove Spring	5	standing	4.40	93
978	George Spring	19	flowing	1.4	----
982	Goshawk Spring	4.4	flowing	0.10	66
983	Grapevine Spring	3	standing	0.03	100
855	Griffiths Spring	3.5	flowing	0.31	79
989	Homestead Spring	14	flowing	0.18	45
545	Hunter Spring	0	dry	0.14	39
1004	Jones Spring	7	standing	0.00	100
546	Keller Spring	5	flowing	1.40	100
1011	Lauren Spring	9.5	flowing	0.39	79
1014	Leopard Frog Spring	8	flowing	0.12	84
1032	McFarland Spring	5.2	flowing	0.31	----
181912	North of Willard Spring	59	standing	1.00	68
578	One Hundred One Spring	20.5	flowing	0.33	100
144	Pivot Rock Spring	10	flowing	13.00	100
1075	Rock Top Spring	1	dry	0.01	21
782	Sawmill Spring	4.5	flowing	0.03	73
226652	Spikerush	3	flowing	0.063	----
1096	Strahan Spring	5	flowing	0.68	76