Analysis of Nonnative Plant Species Invasion of Springs Within Coconino National Forest

Submitted by Jeri Ledbetter

Introduction

Springs are among the most biologically diverse of habitats, particularly in arid regions. (Stevens and Meretsky 2008). Isolated by the harsh surrounding desert, aridland springs often support abundant wildlife and rare and endemic species. Yet in spite of the critical nature of water in desert landscapes, springs ecosystems are largely unprotected, inadequately studied, and poorly mapped.

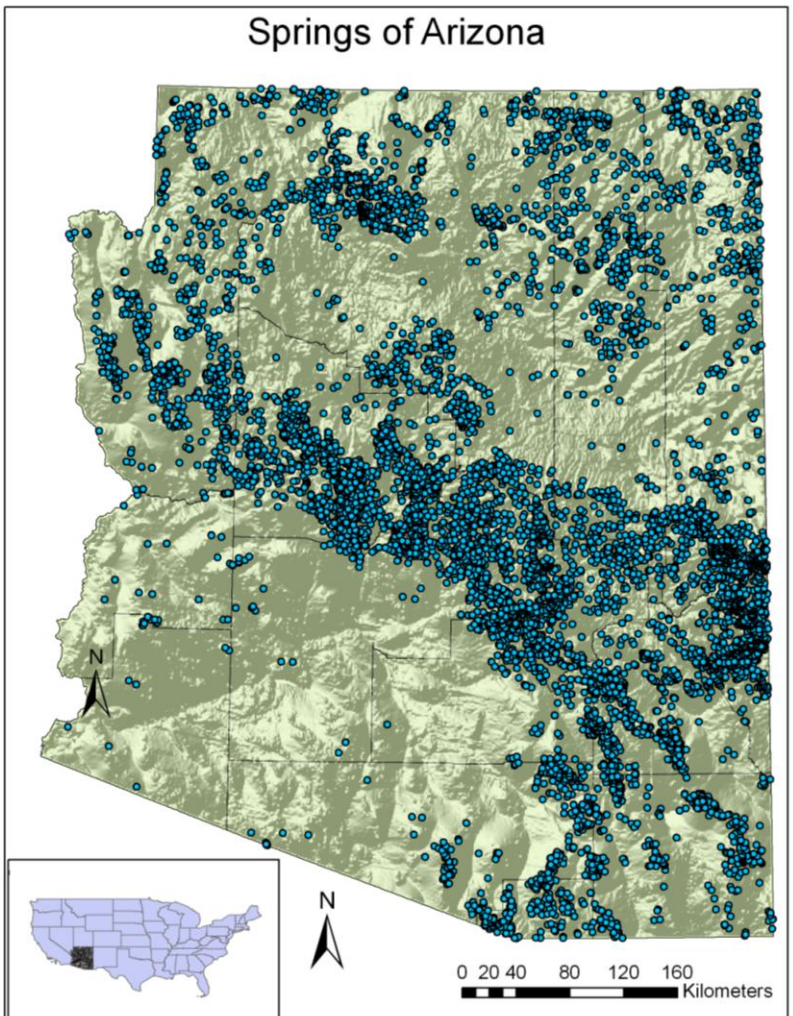


Figure 1. Compilation of available data for 10108 Arizona springs. Data provided by ALRIS (1993 & 2008a), Dick Fleishman (2009), Tribal governments, and individual researchers. Produced using ArcEditor©, used here for educational purposes only.

Afforded little protection, these fragile resources are some of the most threatened ecosystems in the world, having been heavily exploited by humans for thousands of years. Diverted for potable water, stock, irrigation, and mining, few springs ecosystems remain intact (ibid).

Little is known about springs. Although much energy and funding has been devoted to understanding 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 (Nabhan 2008). Only a few individual sites have been extensively studied, and until recently there has been no systematic effort or methodology to survey springs across a landscape (Stevens and Meretsky 2008, Stevens et al 2010).

In many areas we lack even the most basic of information about springs—the location. Arizona, the second-driest state in the U.S., has the second-highest density of mapped springs (ibid). Yet it could have the highest density, as many of Arizona's features remain unmapped. Although several GIS springs layers exist for Arizona, none are complete, and each contains features not included in the others (ALRIS 1993 and 2008a). Figure 1 represents a compilation of these spring layers, as well as data from land management agencies and individual researchers, into a springs geodatabase. Although this geodatabase contains the most complete data available, many springs are incorrectly located or are missing; many are unnamed and not included on topographic maps.

In an effort to enhance understanding and stewardship of these resources, the Springs Inventory Protocol and accompanying database was developed to study and assess the ecological health and functionality of springs (Stevens, Springer, and Ledbetter 2010). A comprehensive evaluation involves a site visit by a team of experts, collecting data in 12 categories, including geomorphology, soils, geology, solar radiation, flora, fauna, water quality, flow, georeferencing, and cultural resources, as well as an assessment of the site's condition and risks to its resources. The information collected in each category is quite complex, and many of the data are interrelated. The Springs Inventory Database is designed to provide a framework to enter and compile this information, and to analyze biological, physical, and cultural relationships, many of which are poorly understood. This analysis will focus on relationships between the density of non-native plant species and several independent variables.

Keller Spring (Site #546) on the Mogollon Rim, surveyed 7/4/2010. This unmapped spring was located during a 2001 survey by US Forest Service personnel (Fleishmen 2009). Photo by Glenn Rink.

In Northern Arizona, plant communities at springs contrast starkly with the surrounding desert vegetation, supporting species such as columbine, monkey flower, horsetail, sedge, orchid, cottonwood, and willow. Unfortunately, conditions that support such diversity of native species provide equal opportunity for invasive nonnative plants. Nonnative plants crowd out native species, and alter habitat structure and fire frequency. Thus, nonnative invasion exacts a disproportionately large impact on regional biodiversity (Stevens 2010a). Nonnative plant seeds may be dispersed by wind, water, and movement of animals. Many are transported and introduced by humans, either intentionally or accidentally. This analysis explores what conditions contribute to increased invasion of nonnative species into springs ecosystems.

Research Questions

What environmental factors influence variation in nonnative plant species richness?

The areas of the microhabitats associated with springs vary widely, ranging from a few square meters to dozens of hectares. As larger areas are likely to support more species—native and nonnative—this variable could influence the results (Stevens 2010b).

Spring discharge also varies dramatically, oozing a few drops per minute or gushing hundreds of cubic feet per second. Although some springs produce a surprisingly constant seasonal discharge, many produce flows that are erratic, intermittent, or ephemeral. Vegetation species richness—whether native or introduced—would be expected to be influenced by flow.

Aspect may also affect species richness. However, this dataset is too small to contain a sufficient number of generalized aspects for a meaningful analysis (Stevens 2010b). Therefore, aspect was not considered in this study.

Is nonnative plant species richness related to road proximity?

Throughout our evolutionary existence, humans have out of necessity lived and traveled near water resources (Stevens and Meretsky 2008). In the arid southwest, cultural and historic sites were often located near springs. Frequently traveled routes often passed by these as well as other known water sources. Modern humans follow the same pattern, and roads are often located near water resources. Springs that are located near roads are also more likely to be subject to human visitation, and may therefore be more vulnerable to nonnative species invasion. A second objective was to develop a predictive model of road proximity impacts on nonnative species density.

Is nonnative plant species richness related to whether or not a spring has been mapped?

One variable of particular interest is whether the spring has been included on topographic or Forest Service maps. Unmapped springs are less likely to be subject to human visitation and manipulation than those that are mapped. And as previously noted, many nonnative plant seeds may be transported by humans, intentionally or inadvertently. One objective of this study was to analyze the relationship, if any, between nonnative species density for mapped vs. unmapped springs.

Several other factors may also influence species richness. Those considered in this analysis are listed on Table 1.

Table 1. Factors considered in this analysis that may influence nonnative vegetation density.

Area	Larger areas are likely to support more species, both native and nonnative. The area of microhabitat associated with each spring could therefore influence nonnative plant species richness.
Fire history	Fire can dramatically alter vegetation communities, leaving them more susceptible to nonnative plant species recruitment.
Flow	Some spring discharge is very low, and some flows are erratic, intermittent, or ephemeral. As presence of water can affect vegetation communities, this variable could affect species richness.
Geomorphic diversity	Geomorphic diversity is calculated using the Shannon-Wiener equation, to measure the diversity of the microhabitats associated with springs. This is calculated as the sum of Log10(Area/TotalArea). Geomorphic diversity may affect plant species richness.
Grazing history	In the southwest, areas surrounding springs have historically been heavily used for grazing cattle. Feed may contain nonnative seeds; livestock can disburse them throughout the allotment. Species richness of a spring may be affected if located within a cattle grazing allotment.
Slope	The degree of slope strongly influences the type of vegetation found at a site; this may also affect plant species richness.
Solar radiation	The amount of solar radiation reaching a site can affect vegetation diversity; therefore this variable could also affect plant species richness.
Stream proximity	Rheocrene springs—those located in the bottom of a drainage—may be more susceptible to nonnative species invasion due to increased flood disturbance connectivity.
Mapped status	Many springs have never been included on topographic maps. For this reason they are relatively unknown, and may not have not been subject to as much human visitation and/or manipulation as springs that have been mapped. This relative isolation could influence nonnative plant species richness.
Road proximity	Springs that are located near roads may be more likely to be visited by humans, and may be more vulnerable to nonnative species invasion.

Methods

Study Area

Springs of Arizona are significantly clustered. Moran's I analysis of springs within the 83 Arizona hydrologic subbasins returned an index value of 0.3007, reflecting less than 1% likelihood that the clustered pattern could be the result of random chance (Figure 2). This pattern is particularly pronounced along the Mogollon Rim—a spectacular escarpment that extends nearly 200 miles across central Arizona and defines the southwestern boundary of the Colorado Plateau.

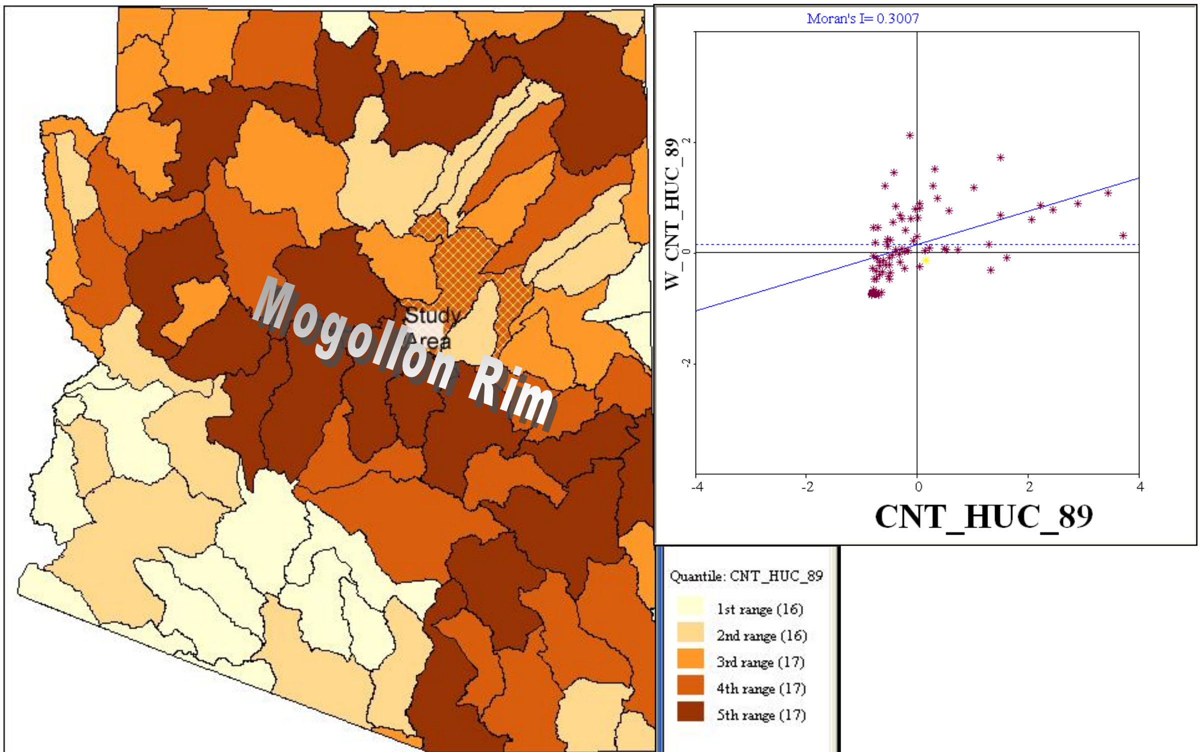


Figure 2. Moran's I scatterplot analysis and choropleth map of distribution of 10108 springs within 83 subbasins. This analysis reveals significant clustering along the Mogollon Rim. Data provided by AGIC (2009), ALRIS (1993 & 2008a), Dick Fleishman (2009), and individual researchers. Produced using GeoDa statistical software, used here for educational purposes only.

The study area is located along this escarpment, in the East Clear Creek drainage of Coconino National Forest in Northern Arizona. During the summer and fall of 2009 and 2010, a team led by springs ecologist Dr. Larry Stevens surveyed 32 randomly-selected springs within this area (Figure 3).

Many of these springs are unmapped and are missing from Arizona GIS layers, but were discovered during a survey in 2001 by US Forest Service personnel (Fleishman 2009). The Forest Service completed the random selection and provided a list of sites to be surveyed. The surveys produced a robust dataset in all 12 categories, including native and non-native plant diversity, expressed as species richness as well as density per square meter. Table 2 contains the list of surveyed springs that are included in this study.

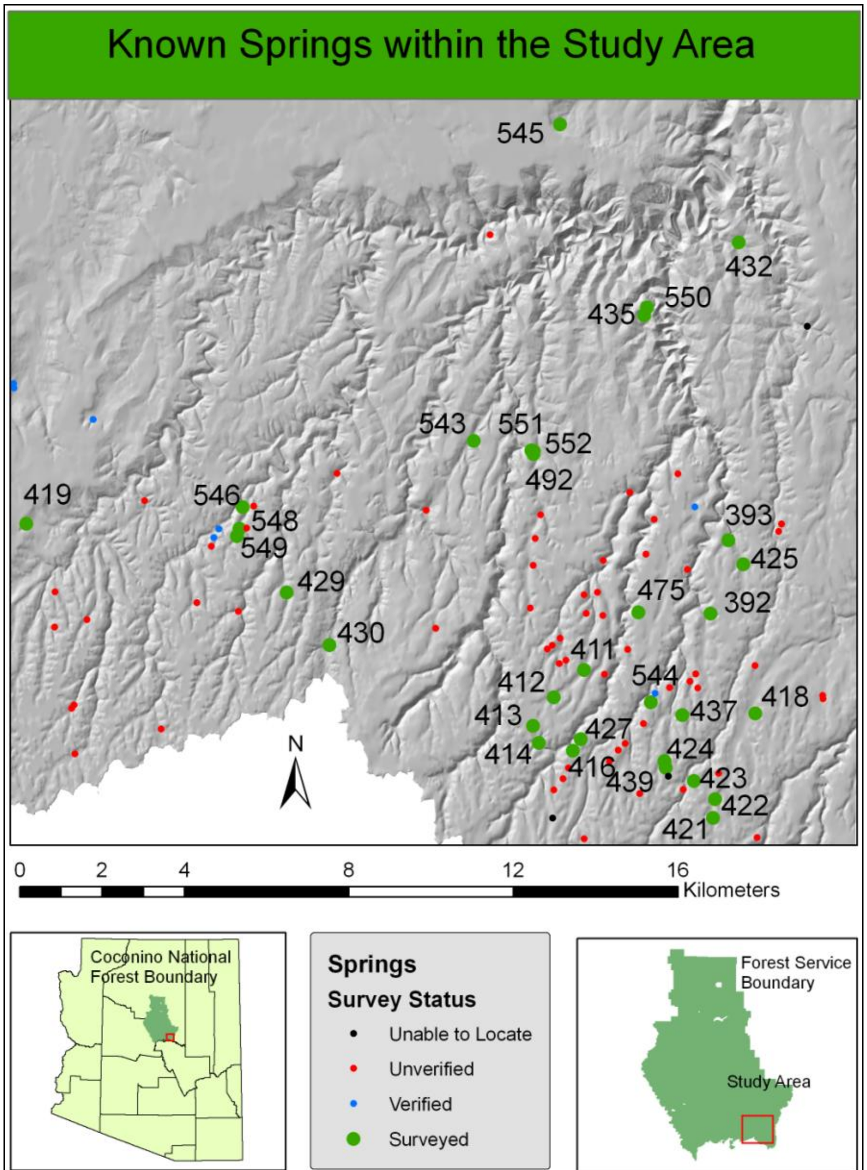
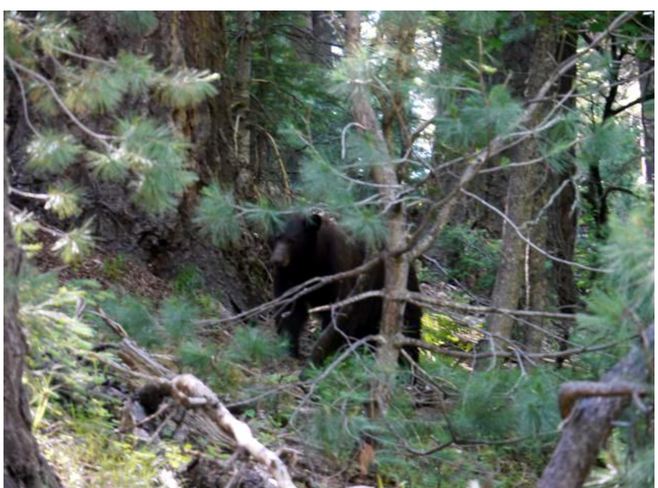


Figure 3. All known springs within study area. Surveyed springs included in the study are listed in Table 2. Data provided by ALRIS (1993 and 2008a), and Fleishman (2009). Produced using ArcEditor©, used here for educational purposes only.

Table 2. Surveyed Springs Included in Analysis.

Site ID	Spring Name	Location Source	Elevation (meters)	X Coord NAD 83	Y Coord NAD 83	Survey Date
392	Dane Spring	ALRIS	2246	486316.1	3813918	7/7/2009
393	West Moonshine Spring	ALRIS	2220	486751.1	3815703	9/19/2009
411	Merritt Spring	ALRIS	2274	483247.5	3812541	8/22/2009
412	Whistling Spring	ALRIS	2296	482510.1	3811884	8/21/2009
413	FS139C Spring Pond	Ledbetter	2333	482006.6	3811181	8/23/2009
414	Barbershop Spring	ALRIS	2292	482150.1	3810776	8/22/2009

Site ID	Spring Name	Location Source	Elevation (meters)	X Coord NAD 83	Y Coord NAD 83	Survey Date
416	Cliffside Springs	Fleishman	2322	482970.2	3810584	9/13/2009
418	Lower Buck Spring	DLG	2275	487401	3811490	9/19/2009
419	Poverty Spring	ALRIS	2189	469691.5	3816099	9/11/2009
421	Upper Buck Spring High	Ledbetter	2348	486376	3808946	9/12/2009
422	Upper Buck Spring	ALRIS	2313	486429.1	3809404	9/13/2009
423	Dora Springs	Fleishman	2313	485916.6	3809842	11/10/2009
424	Morningcloak Springs	Fleishman	2314	485193.9	3810325	9/20/2009
425	Moonshine Spring	ALRIS	2226	487108.1	3815115	9/19/2009
427	Hidden Springs	Fleishman	2309	483165.5	3810866	10/10/2009
429	Hi Fuller Spring	ALRIS	2231	476020.8	3814427	7/4/2010
430	General Springs	ALRIS	2182	477061.2	3813147	9/21/2009
432	Lockwood Spring	ALRIS	2098	486999.7	3822940	9/18/2009
435	Quail Spring	ALRIS	2107	484705.9	3821165	7/1/2010
437	Coyote Spring	ALRIS	2281	485632.8	3811452	9/19/2009
439	Royal Bull Spring	Ledbetter	2312	485225.7	3810164	9/20/2009
475	Lara Springs	Fleishman	2249	484560.5	3813942	9/12/2009
492	Pinchot Spring channel	Ledbetter	2192	482010.5	3817791	7/2/2010
543	Quien Sabe Spring	ALRIS	2136	480563.8	3818120	7/2/2010
544	Monkshood Spring	Fleishman	2275	484870.1	3811755	7/3/2010
545	Hunter Spring	ALRIS	2204	482663.5	3825812	7/3/2010
546	Keller Spring	Fleishman	2177	474953.3	3816506	7/4/2010
548	Monongye Spring	Fleishman	2198	474875.4	3815985	7/4/2010
549	Drier Spring	Fleishman	2206	474814.5	3815797	7/4/2010
550	Lower Quail Spring	Fleishman	2100	484777.8	3821360	7/1/2010
551	Pinchot Springs west	ALRIS	2157	481965.8	3817881	7/2/2010
552	Pinchot Springs east	Ledbetter	2153	482027.5	3817862	7/2/2010



American black bear (*Ursus americanus*) near Monkshood Spring (#546) during survey on 7/3/2010. Photo by Frank Romaglia.

Throughout the study area, tall stands of ponderosa pine (*Pinus ponderosa*) dominate the landscape. With elevations ranging from 2100 to nearly 2350 meters (6800 – 7700 feet), the many springs support abundant wildlife, including elk, deer, a variety of birds, bobcat, coyote, and an occasional American black bear (*Ursus americanus*).

Vegetation Data

During a comprehensive survey, the team identifies geomorphic microhabitats (polygons) associated with the site (Stevens et al 2010). These areas result from different geomorphic processes. The team's botanist develops a complete plant list within the microhabitats associated with the spring, and estimates the percent cover represented by each species. These data are entered into the Springs Inventory Database, which calculates and reports a number of variables for the site, including density and richness of nonnative species. (See Figure 4) Using the Spring ID number, tables from this database were joined with the springs geodatabase.

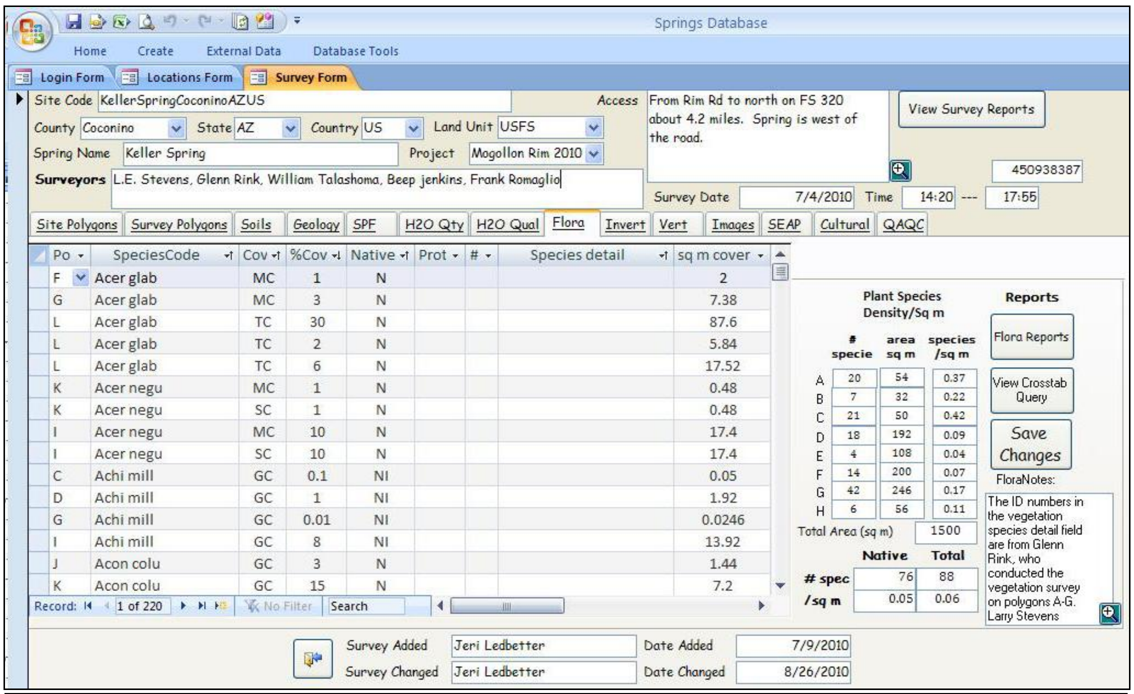


Figure 4. View of the Vegetation data entry page in the Springs Inventory Database. Data from Keller Spring (Spring ID #546). Percent cover of each species of plant is entered for each microhabitat at the site. The native status for each species is automatically generated from lookup tables in the database, or can be overridden by the survey botanist.

Other Data Sources

Several GIS layers used in this analysis were downloaded from the US Forest Service website. These included the Forest Service administrative boundary (2009b), grazing allotments (2009c), and fire history perimeter data (2009a). Other data sources included 10-meter DEM raster elevation data for the study area (ALRIS 2004), a Coconino County roads layer (AGIC 2008), the Arizona county boundary layer (AGIC 2008).

Preparation of Data

Prior to analysis, all data layers were projected to NAD_1983_HARN_UTM_Zone_12N to match the springs geodatabase layer. Two 10-meter DEMs were merged and clipped to provide elevation coverage, and all raster and vector layers were clipped to the match the extent of the study area.

Analyses

Area, elevation, geomorphic diversity, flow, solar radiation, and mapped status values for each spring were acquired through the survey process and/or calculated by the Springs Inventory Database. Spatial layers were created as follows:

1) Proximity to roads – Using the Distance Straight Line tool in ArcMap's Spatial Analyst, a raster layer was generated from the Coconino County Roads layer (AGIC 2008). This layer was then reclassified manually into 10 categories. These ranged from 1, for springs within 25 meters of a road, to 10, for those springs more than 400 meters from a road. The reclassified raster layer was converted to a vector layer. Using Spatial Join, these classified values were added to the springs geodatabase table.

2) Slope – As spring features are mapped as point data, obtaining slope values from 10-meter DEMs would return the value only in the cell where the point is located (ALRIS 2004). This would not accurately reflect the values of springs ecosystems, as their areas range from 44 to 6384 square meters. Therefore, a slope layer was generated from 10-meter DEMs, but generalized to four times the size, using the mean value of combined cells. From the resulting raster layer, a 5 degree contour vector layer was created. Using the Spatial Join tool, a generalized slope for each spring was added to the springs geodatabase table.

3) Proximity to streams – A raster layer calculating the distance from each cell to the nearest stream was created using The Distance Straight Line tool. The resulting raster layer was reclassified using defined intervals of 50 meters, converted to a polygon layer, and joined with the springs layer.

4) Fire and grazing history – A polygon layer of fire history, compiled by the US Forest Service (2009a), included fires over ten acres (4.5 ha.) between 1931 and 2009. The grazing allotment polygon layer denotes land currently available for livestock grazing. Although some areas have recently been closed to livestock, the long history of this use continues to affect the landscape. Therefore, use of the allotment data is appropriate for this application. Boolean fields were added to the springs layer for fire and grazing history. These were edited using a spatial join with the fire and grazing layers.

5) Solar radiation –The solar radiation at the spring source is estimated using sunrise and sunset data collected in the field using a Solar Pathfinder (2010). These data were used for the analysis. An alternative method was evaluated, however, using the Solar Radiation Spatial Analyst tool in ArcMap (ESRI 2010). A value was calculated for the total solar energy at each spring using the merged DEM, clipped to the study area. This process produced raster layers in watt hours per square meter. First, the tool was used to generate 200-meter cells with solar radiation estimated in 1-hour intervals. A second layer was set to produce 100-meter cells, estimated in ½-hour intervals. Using spatial join, these values were added in new fields to the springs layer, then converted to megajoules per square meter so they could be compared with the field data collection method.

The springs table was then exported into Microsoft Excel for analysis. Dr. Larry Stevens (2010b) demonstrated the use of Statistica software to conduct a Pearson Correlation analysis of the numeric data, and a nonparametric Kruskal -Wallis median analysis of the Boolean data.

Results

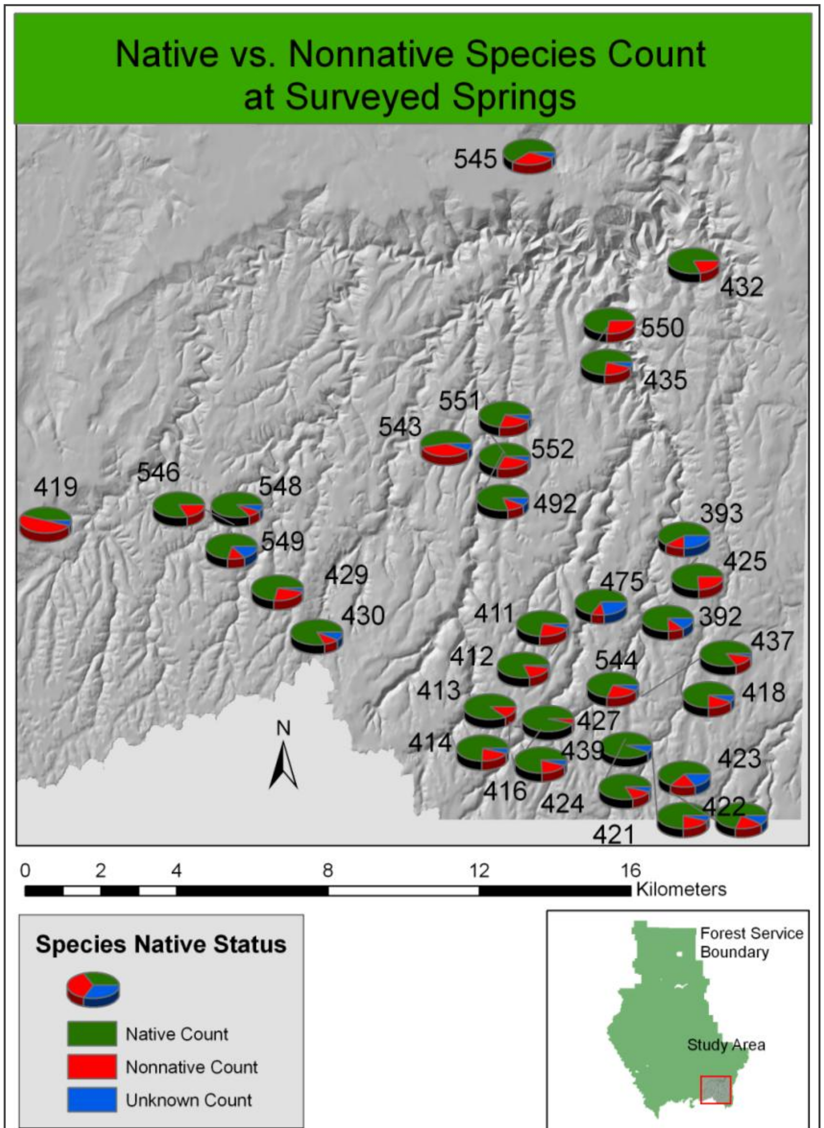


Figure 5. Native status of plant species found at surveyed springs. Data provided by AGIC (2008), ALRIS (1993 & 2008a), Fleishman (2009), USDA (2010), and Stevens (2010a). Produced using ArcEditor©, used here for educational purposes only.

Plant Species Native Status

Figure 5 displays the results of native status analysis of vegetation at each surveyed spring. Surveyors identified most of the plants at the site, and collected samples of unknown species for later identification. Native status for each species is based on the USDA Plants Database (2010). Dr. Stevens (2010a) determined the native status of those plants only identified to family or genus, as these are not available from the USDA site. Some species remain unidentified, their native status unknown. Some sites, such as Poverty Spring (#419), have a very high ratio of nonnative species. Heavily grazed, its source is obliterated by a road. Royal Bull Spring (#439), was located during the Forest Service Survey in 2001. Surveyors found no nonnative species at this site in 2009.

Area

Consistent with standard analysis of the species-area relationship (MacArthur and Wilson 1967), total plant species richness (S) at each site and total springs ecosystem area (A) were $\log_{10}$ transformed (Stevens 2010b). Total plant species density was weakly, positively related to area (Figure 6). Because this relationship was weak, with R2 – 0.246, total plant species richness was not adjusted for area in the subsequent analyses.

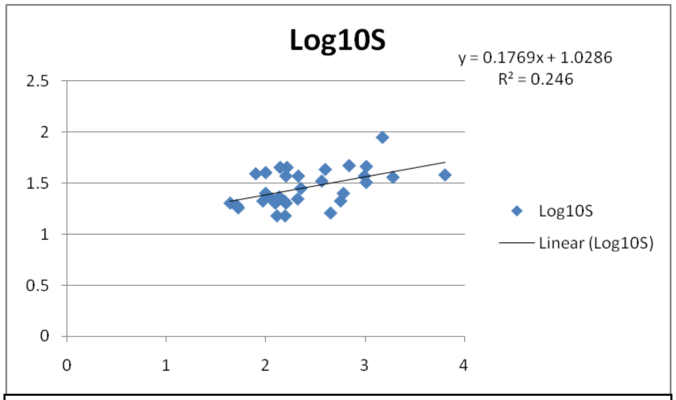


Figure 6. Results of Log10 transformation of total species richness and site area. Chart produced using Microsoft Excel 2007.

Proximity to Streams

The results of the stream proximity analysis did not reflect what the crews determined during the surveys. This is primarily due to inaccuracies of the springs layer used for the analysis. Some springs in the bottom of stream channels were calculated as being quite distant from them. For example, Lara Spring (#475) emerges in a channel, yet was calculated at 140 meters from a stream. Similarly, Quail Spring (#435) is the source of a stream's flow, yet was calculated as being 316 meters distant. Due to such inaccuracies, these data were not included in the analysis. The calculation can be repeated when a more accurate streams layer become available.

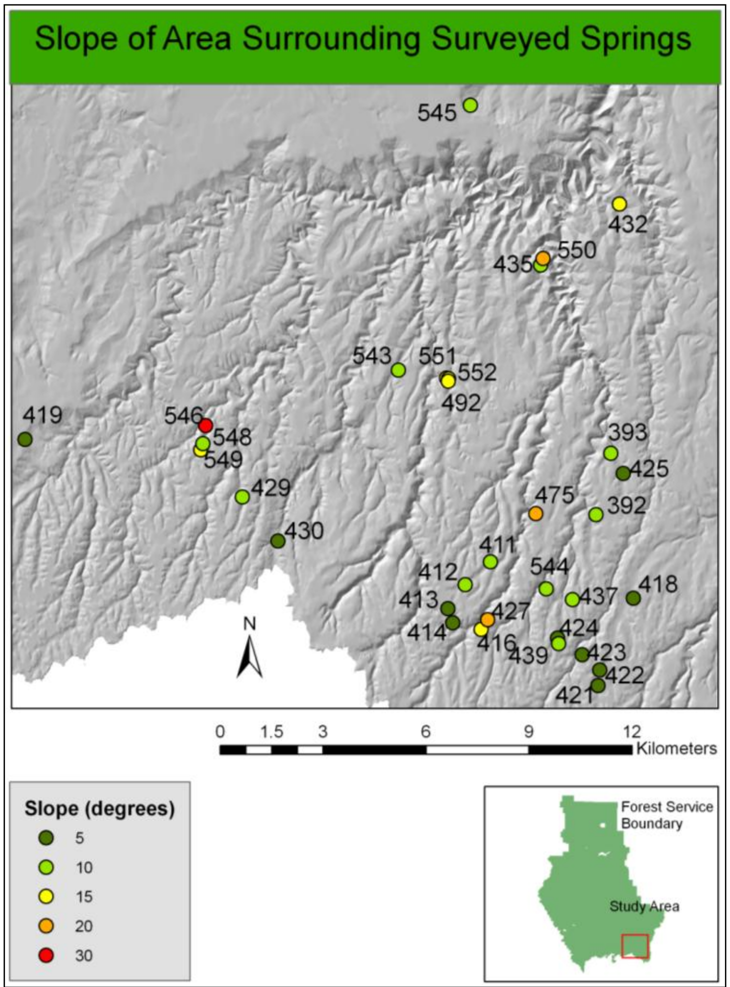


Figure 7. Results of Slope Analysis. Data provided by ALRIS (2004). Produced using ArcEditor©, used here for educational purposes only.

Slope

Results of the generalized slope analysis are presented in Figure 7. The results are reasonably accurate when compared with field data, and were used in subsequent analysis.

Fire History

None of the springs intersected any of the polygons included in the fire history dataset provided by the US Forest Service (2009a).

Grazing History

Although some springs are not located on current grazing allotments, the entire area has been subject to heavy grazing for decades. The available grazing allotment layer did not reflect this historic use (USFS 2009b). Therefore this variable was not directly considered during the analysis. However, as springs in areas of high slope are less accessible to livestock, historic use is indirectly reflected in the results.

Solar Radiation

Results from the solar radiation analysis using the ArcView Spatial Analyst tool were not consistent with those collected manually during field surveys. Of 32 calculated values, 26 were lower and 6 were higher than those produced from field testing. Only 13 calculated values were within 10% of field measurements, and 3 were within 5%. The greatest error was at a spring emerging from a cave against a west-facing cliff, in the bottom of a steep drainage. This supported a suspicion that springs in areas of greater slope would be less accurate than those in flatter areas with little obstruction; however, this was not the case. Sites with the 13 more similar values ranged in slope from 5 to 20 degrees. Recalculating the values using smaller cells degraded, rather than improved the results. Therefore, field estimates of solar radiation reaching the sites were used for this analysis.

Proximity to Roads

The study contains approximately 1260 kilometers of dirt roads, varying from relatively well-maintained two-laned roads to rough, single-laned jeep trails. Many roads were constructed to provide access to springs. As a result, nearly all springs are located very close to roads. Ten were within 25 meters of a road. One road was built on top of the source of Poverty Spring (#419), the flow piped into a livestock tank nearby. Only four of the surveyed springs are located more than 200 meters from a road.

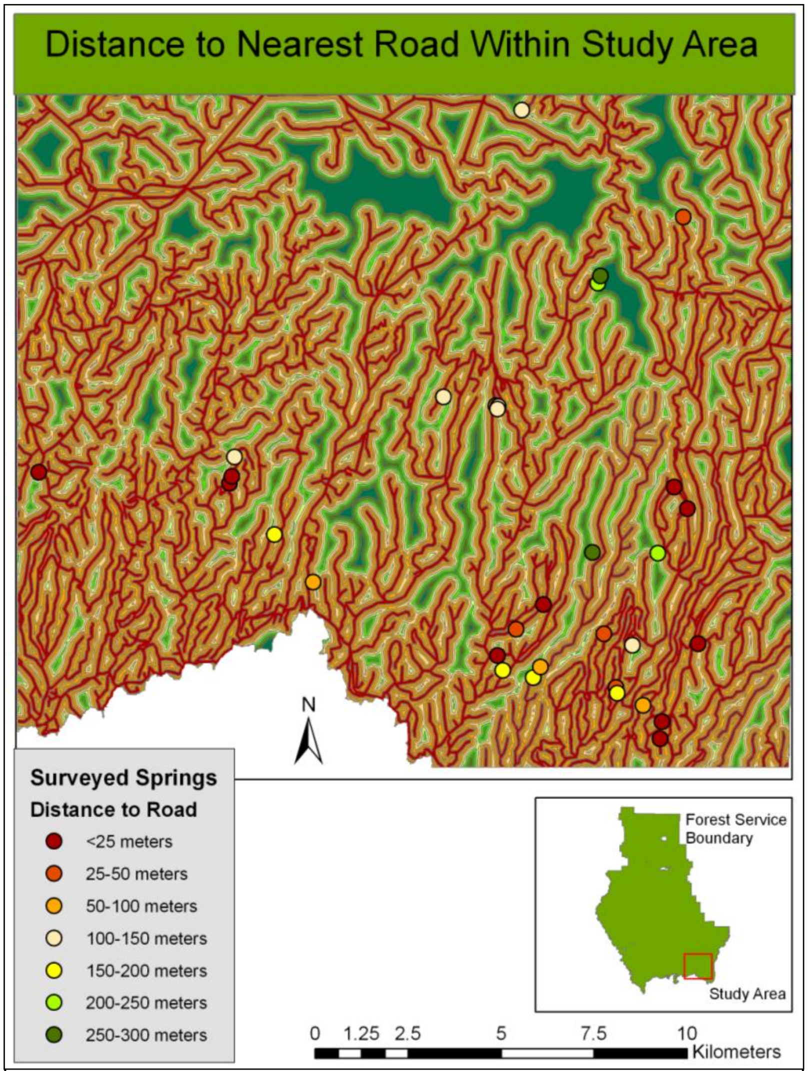


Figure 8. Results of proximity to roads analysis. Data provided by AGIC (2008), ALRIS (1993 & 2008a),and Fleishman (2009). Produced using ArcEditor©, used here for educational purposes only.

This is not due, as one might easily suspect, to laziness on the part of surveyors. As noted earlier, the survey list was selected randomly. Dr. Stevens, who often states, "If you're not bleeding, it's not random," required adherence to the prioritized list. Further, analysis of the known springs in the study area revealed only 13 of the 102 springs (12%) to be farther than 200 meters from a road.

Figure 9 demonstrates the mean nonnative species richness for surveyed springs, classified by their distance from the nearest road. This graph does not reflect a statistically significant pattern.

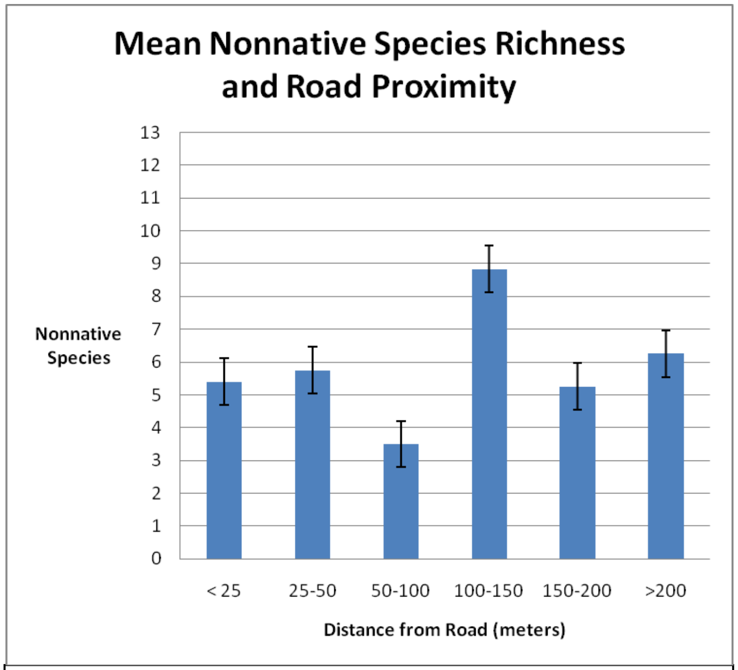


Figure 9. Nonnative species richness compared with distance from the nearest road for all surveyed springs (Stevens 2010b). Data provided by AGIC (2008), ALRIS (1993 & 2008a),and Fleishman (2009). Map analysis was completed using ArcEditor©, used here for educational purposes only. Chart produced using Microsoft Excel 2007.

What Environmental Factors Influence Variation in Nonnative Plant Species Richness at Springs?

A multivariate analysis resulted in the matrix shown in Table 3 (Stevens 2010b). Highlighted correlations reflect significant relationships. Some of these results are expected. For example, there are direct relationships between road distance and slope, and between elevation and slope. The negative relationship between elevation and the number of nonnative species could also be anticipated, as spring elevations ranged from 2100 to 2350 meters. There was no evidence of a relationship between the number of nonnative species and any of the other dependent variables tested.

Table 3. Pearson Correlation Analysis of Numeric Variables

	Area	Slope	Road Distance	Geomorphic Diversity	Elevation	NN Species	Solar Radiation	Flow
Area	1.000	-0.113	-0.008	0.177	-0.129	0.050	0.196	0.271
Slope	-0.113	1.000	***0.444***	0.348	***-0.395***	0.105	-0.287	-0.034
Road Distance	-0.008	***0.444***	1.000	0.221	-0.271	0.140	-0.200	0.059
Geomorphic Diversity	0.177	0.348	0.221	1.000	-0.196	0.220	***-0.460***	0.011
Elevation	-0.129	***-0.395***	-0.271	-0.196	1.000	***-0.492***	0.171	-0.217
Nonnative Species	0.050	0.105	0.140	0.220	***-0.492***	1.000	-0.144	-0.122
Solar Radiation	0.196	-0.287	-0.200	***-0.460***	0.171	-0.144	1.000	0.159
Flow	0.271	-0.034	0.059	0.011	-0.217	-0.122	0.159	1.000

Is nonnative plant species richness related to road proximity?
The multivariate analysis revealed no statistically significant relationship between the number of nonnative species and the proximity to roads. As no springs were located more than 300 meters from a road, and only a few more than 200 meters away, the significance of these results is limited. It would be worthwhile to analyze a larger landscape that includes areas with fewer roads, offering a greater variation of road proximity.

Is nonnative plant species richness related to whether or not a spring has been mapped?
As mentioned earlier, 13 of the surveyed springs are not included on topographic or Forest Service maps. These were found in 2001 when Dick Fleishman (2009) of Coconino National Forest directed personnel to locate additional springs. These relatively unknown sites are less likely to be visited than are mapped springs. They are also less likely to have been manipulated by humans, as exploited water resources tend to be included on maps.

A comparison of mean nonnative species richness revealed a statistically significant difference, as shown in Figure 10. The mean of nonnative species at the 13 unmapped springs was 4.15, while at the 19 mapped springs it was 7.16. A nonparametric Kruskal-Wallis median analysis ($\chi2 = 5.783$, df = 1), resulted in a P-value of 0.016 (Stevens 2010c).

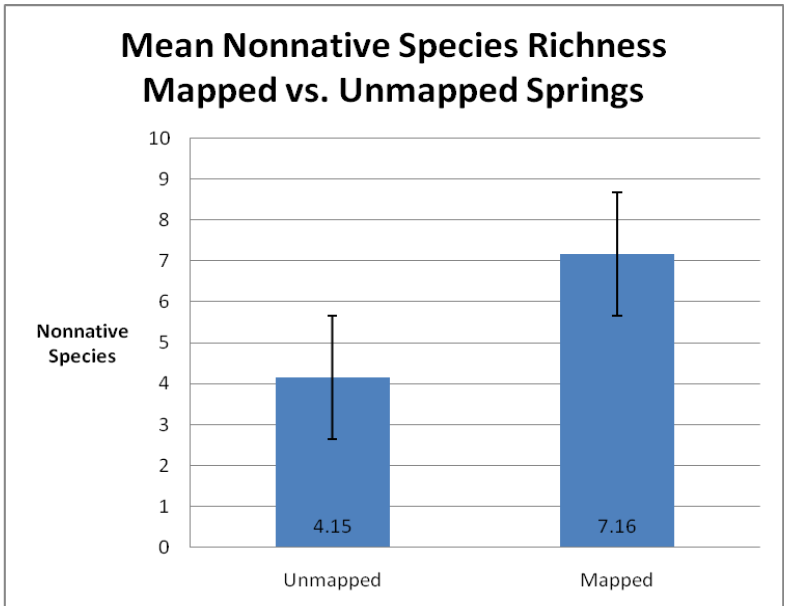


Figure 10. Nonnative species richness compared with mapping status for surveyed springs. Chart produced using Microsoft Excel 2007.

Mapped springs have a 1.7-fold greater nonnative plant species richness than do unmapped springs. However, neither nonnative plant species density per square meter nor the percent of nonnative plant species were statistically different, each returning a P-value greater than 0.47 (ibid).

Figure 11 reflects the mapping status of surveyed springs, classified by their nonnative species richness.

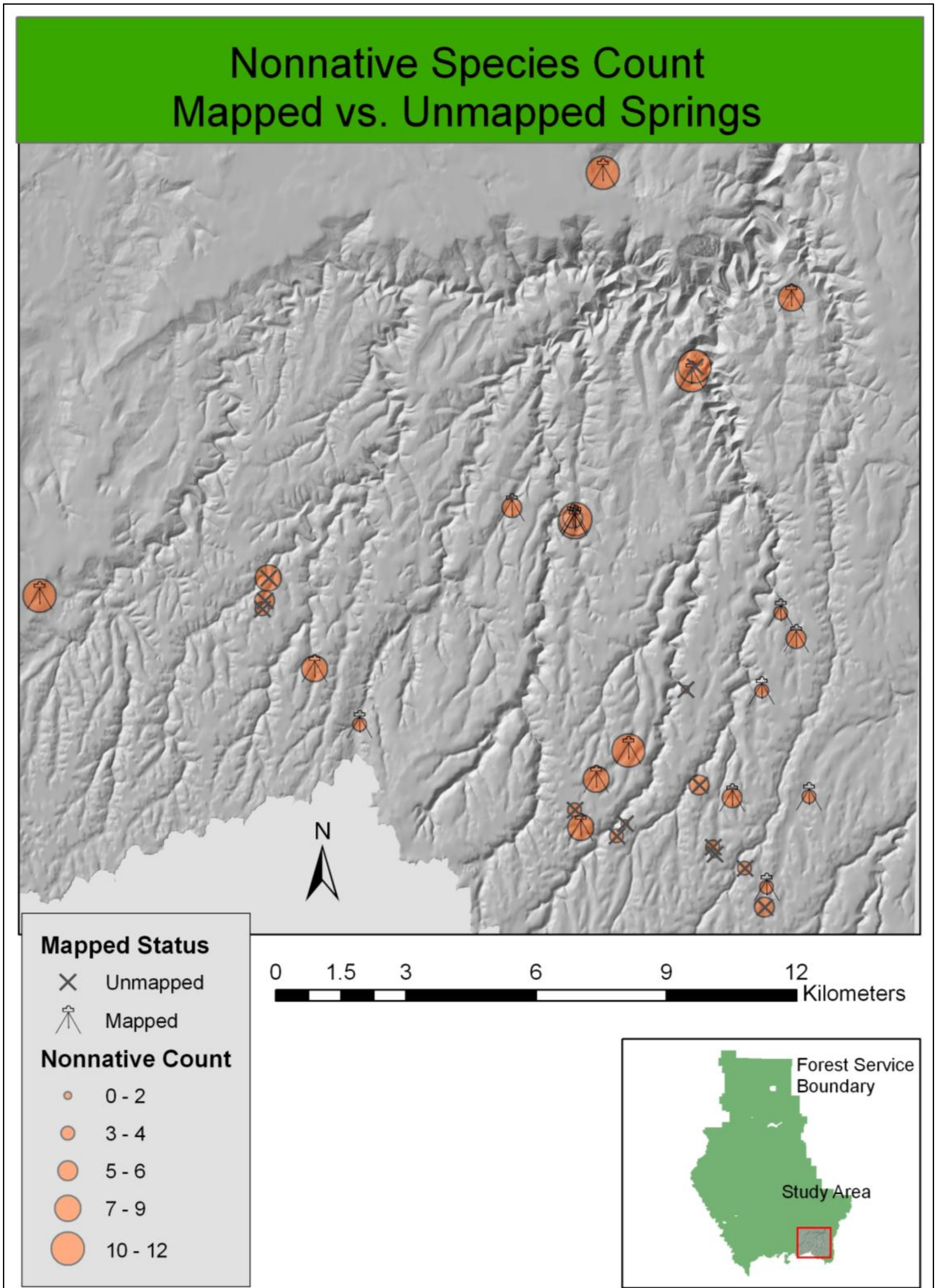


Figure 11. Comparison of nonnative species richness with mapped status of surveyed springs. Data provided by AGIC (2008), ALRIS (1993 & 2008a), Fleishman (2009), and USDA (2010). Produced using ArcEditor©, used here for educational purposes only.

Conclusions

Although this analysis relied upon a robust dataset covering many variables, the number of samples was admittedly small. A larger dataset would offer better insight into the relationships between the dependent variables relating to nonnative species populations at springs.

However, this effort did reveal a statistically significant relationship between nonnative plant species richness and whether or not a spring has been mapped. Springs that are neither depicted on maps nor included in GIS layers are likely to be in better ecological condition, and may be worthy of future study and protection. This analysis provides a compelling argument for land managers to locate these resources in order to protect them. Yet it also offers an argument against including them on future maps.

This study will help inform the National Forest Service during their 20-year forest plan revision by identifying springs with high native plant biodiversity, and beginning to develop a model to understand what variables present the greatest risks to these ecosystems.

Acknowledgements

The field work for this project was supported through a grant to Grand Canyon Wildlands Council to the Pulliam Foundation. ESRI generously donated the software used for the analysis, ArcView and Spatial Analyst, through TechSoup.com in 2009. Many volunteers participated in collecting data, including Hopi Tribal members Beep Jenkins, Eric James, and William Talashoma, who also assisted with data entry. Glenn Rink conducted many of the vegetation surveys, and assisted with quality control of data entry. Larry Stevens provided expertise and training in following the inventory protocols which he has developed, as well as assisted with statistical analysis of the data. Other field participants and volunteers included RJ Johnson, Valerie Hallam, Aryn LaBrake, Virginia Igoe, Eric North, Julaire Scott, Christina Davis, Denise Hudson, Karissa Ramstead, students of Flagstaff Arts and Leadership Academy, Frank Romaglia,

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