Evaluating the Treatment of Salt Cedar Along the Lower Salt River

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AP Research

March 31, 2024

Word Count: 4194

Abstract

Invasive salt cedar plants are an increasing threat to riparian habitats along the Lower Salt River. Literature has demonstrated the negative implications of dense salt cedar stands including reduction in biodiversity, competition against native plants, and increases in soil salinity. While there are many avenues for salt cedar control, Ecoculture, a company managing the Lower Salt River Restoration Project, uses cut-stump chemical control to mitigate the impacts of salt cedar. Often the adverse effects of salt cedar can extend post treatment, known as the legacy effect. However, this has only been studied in relation to biological control. The following research paper implemented a causal comparative study to evaluate how Ecoculture's treatment methods affected soil salinity by comparing electrical conductivity (EC_E) values across varying salt cedar extents (dominant, treated, present, and control). The results demonstrated that salt cedar creates potentially harmful concentrations of salts in the surrounding soil. There was an identifiable legacy effect, or persistence of adverse salt cedar effects; treatment consistently had the second highest EC_E readings. However, when examining the year each site was treated, there was not a clear correlation between time since treatment and salinity. The data also justified the benefit of treating salt cedar stands, with an approximate 55% decrease in salinity. Overall, this research could be used to inform further restoration programs along the Salt River and highlight the need to choose restorative vegetation that can be maintained in the post-treatment areas still exhibiting abnormal salinization.

Introduction

Ecosystems surrounding rivers bridge aquatic and terrestrial habitats. These are commonly referred to as riparian zones and they are key components of environmental health. Because of their unique position in the environment, both aquatic and terrestrial species rely on them. Furthermore, they are widely utilized by humans for resources, recreation, and culture. Riparian habitats have the power to protect wildlife, cycle nutrients, promote vast biodiversity, and build climate resilience (Gregory et al., 1991; Noss et al., 1996). Therefore maintaining these areas improves the functional integrity of surrounding ecosystems. In an environmental context, functional integrity refers to a system's resilience to internal collapse. Threats like climate change and invasive species continually test this metric in riparian zones. Naiman, with a Ph.D from the School of Aquatic and Fishery Science at University of Washington, along with his colleagues (1993) further describe how properly maintaining these riparian zones have the potential to mitigate issues surrounding land use and the environment. Because so many vertebrate species rely on these habitats, they are key stabilizers of the trophic pyramid in the midst of ecological change. Issues like the balance of drinking water with "long term environmental" requirements are deeply ingrained with riparian ecosystem management. However, due to human interaction these forests have been designated as critically endangered ecosystems (Noss et al., 1996). Compared to pre-settlement levels, areas in Arizona and New Mexico have seen riparian zone losses of up to 90% (Noss et al., 1996).With this information in mind, the decrease in biodiversity is irrefutable. These changes may disrupt the careful balance between habitats. Plant dispersal, soil quality, water quality, biota richness and abundance, and trophic systems could all face degradation (Gregory et al., 1991). Several processes can influence these factors. For example, climate change is a major catalyst for riparian risk, with North

America seeing some of the most drastic shifts (Hultine et al., 2015). This can be attributed to a variety of factors: consumerism, urban sprawl, and local pollution. Rapid acceleration of climate change along with other interferences stemming from human activities affect various species and their communities (Hultine et al., 2015; Naiman et al., 1993). Hunting, irrigating, and introducing exotic species could all increase the risk posed to riparian zones. The Lower Salt River in southern Arizona is of equal importance and faces similar issues. It is a place of recreation, testament to ancient irrigation, and home to sprawling native riparian biodiversity including fremont cottonwoods (Populus fremontii), goodings willows (Salix gooddingii), velvet mesquites (Prosopis velutina), and various fauna (Toy, 2021). Local initiatives, such as the Lower Salt River Restoration Project (LSRRP), are already in progress and addressing some of the most pressing issues threatening Riparian ecosystems. Riparian areas have vast impacts on riverine ecosystem services, or the benefits people can derive from these habitats. Therefore maintaining their health through diligent protection and associated research is key to mitigating environmental damage.

Literature Review

A major concern in riparian zones is the dominance of an invasive species. These infestations can displace native plants and significantly reduce biodiversity (Pyšek et al., 2012). Along the Lower Salt River, salt cedar (Tamarix spp.), initially cultivated to minimize erosion and add decoration, has become a pervasive issue (Jacobs & Sing, 2007).

In arid parts of China with similar ecological profiles, Zeng, affiliated with the State Key Laboratory of Desert and Oasis Ecology, and his team (2020) noted plant diversity's dependence on groundwater access. Hultine, who works on research with the Desert Botanical Garden in

Phoenix, AZ, and his colleagues (2015) reinforce this concept, explaining fremont cottonwood's reliance on shallow groundwater to be absorbed by their lateral root system. Salt cedar directly jeopardizes native ecology by increasing soil salinity that is associated with higher rates of groundwater evaporation (USDA, 2014; Zeng et al., 2020). The scope of this research project does not include groundwater depth despite its pertinence to the topic. Rather, the primary focus will revolve around soil salinity.

Salt cedar alters the soil chemistry through leaf drop decomposition; in turn, this disrupts natural processes, inhibits fungal partnerships, and degrades the cycle of nutrients (Hultine e al., 2015; USDA, 2014). Hultine and his fellow researchers (2015) note how this is especially problematic for cottonwood, a riparian plant that relies on mutual symbiotic relationships with mycorrhizal fungi. One notable means of influencing the soil is by increasing its salt content. This spike in salinity is problematic because it suppresses native plant growth while leaving salt cedar stands largely unaffected (Shrivastava & Kumar, 2015). This biological advantage allows the salt cedar to establish dense populations. Aside from eliminating its competition, high soil salinity caused by salt cedar can cause salt burn in existing trees and kill other biota (J. Eddinger & J. Draper, personal communication, December 7, 2023). An online management guide, pulling data from a 2004 research paper on salt tolerance, identified fremont cottonwoods as moderately sensitive (minimal injuries at soil electrical conductivity (EC) of 3-6 deciSiemens dS/m) and willow species as sensitive (minimal injuries at soil EC of less than 3dS/m) (*Salinity*, 2017). With these species dominating Salt River riparian habitats, their sensitivity to salt emphasizes the urgency of addressing salt cedar invasions.

The United States Department of Agriculture Salt Cedar Management Guide (2014) lists several standard practices for their removal: cultural, physical, biological, and chemical.

Regardless of the chosen method, there is relative agreement that an effective management program considers the potential for revegetation and employs a variety of techniques (Jacobs & Sing, 2007; USDA, 2014). In the case of salt cedar, biological control has been administered using the Eurasian Tamarix leaf beetle that can cause regular defoliation and sometimes kill the plant (Hultine et al., 2015). In their study, Hultine and his team (2015) observed how the treated stands still had negative impacts on fungal relationships that were partially attributed to soil salinity. This persistence was referred to as the "legacy effect" and has only been studied in conjunction with biological control methods.

The most dominant means of salt cedar control, however, is chemical application (USDA, 2014). While this may take several forms, this paper will focus primarily on individual plant treatment through the cut-stump method. This practice is implemented by Ecoculture, the company managing the LSRRP, and involves cutting the stump as low as possible and applying a 10% Imazapyr solution with water and seed oil, followed by native plant cultivation (J. Eddinger & J. Draper, personal communication, December 7, 2023). Cut-Stump treatment is beneficial when one must be highly selective and protect native biodiversity (USDA, 2014).

While salt cedar actively deteriorates riparian areas, it is important to acknowledge the limitations and implications of their removal. Due to willow tree displacement attributed to salt cedar, the willow flycatcher, protected by the Endangered Species Act of 1973, nests in salt cedar stands (J. Eddinger & J. Draper, personal communication, December 7, 2023; USDA, 2014). By jeopardizing the willow flycatcher's reproductive habitats, the endangered population is inadvertently threatened. Complications like these mean that the restoration process requires intentional analysis of confounding variables. In addition to considering the biota salt cedar supports, it is equally important to consider the potential success for the control project. If native plant reestablishment is not feasible, it is unsustainable to pursue salt cedar control (USDA, 2014). Resources would be wasted on ineffective projects that ultimately become dominant salt cedar stands again in the future. Companies do extensive analysis and testing to ensure that the restoration will have the intended results on a given area. Both of these had to be addressed by Ecoculture to justify the Lower Salt River Restoration Project. The Lower Salt River is outside of the willow flycatcher's dominant range (J. Eddinger & J. Draper, personal communication, December 7, 2023). This means that the salt cedar they remove is not actively serving as nesting habitat, and in turn does not further threaten the protected population. The 2017 cactus fires jump started their initiative and made the conditions for native regrowth favorable (J. Eddinger & J. Draper, personal communication, December 7, 2023). This is an instance of secondary succession where organisms have an equal opportunity to reestablish themselves in a given environment, but post-disaster, the soil still remains intact. Based on this, it can be stated that the conditions on the Lower Salt River set the stage for an effective salt cedar control project.

Ultimately this project seeks to evaluate how the cut-stump chemical control method implemented by Ecoculture through the LSRRP affects soil salinity and the existence or extent of a "legacy effect." This will be achieved through a causal-comparative study utilizing existing ArcGIS data and extensive soil sample analysis. Based on the surrounding literature, it is hypothesized that the treatment implemented by Ecoculture has a positive impact on the ecosystem, decreasing soil salinity. It is probable that a legacy effect will emerge and unlikely that treated areas will exhibit the same readings as control sites.

Methodology

Rationale:

In order to effectively evaluate how Ecoculture 's cut-stump chemical control of salt cedar has impacted soil salinity, a detailed methodology was developed to directly compare the variables. This procedure also considers how future restoration projects could be informed using this research. A causal comparative study was conducted because the interaction between the independent variable (salt cedar extent) and the dependent variable (soil salinity) already occurred. This specific method prevents further deterioration of the environment by avoiding the introduction of new variables. While a causal comparative study cannot inform sweeping generalizations, it can be used to determine causation between variables. This procedure further justifies alignment to the research question by implementing ArcGIS treatment site shapefiles directly from Ecoculture. This ensures that the collected data will align with their salt cedar removal initiatives. Collecting samples from a variety of sites with a variety of vegetation minimizes stark outliers allowing trends to be drawn from the two experimental values. Reevaluation and iteration of the methodology were consistently integrated to ensure quality and consistency throughout the data collection process.

Population:

The scope of this project focuses on the Lower Salt River in Mesa, Arizona. This means that conclusions drawn cannot be applied to other scenarios without considering population differences. Because the research question is situated within the context of Ecoculture's treatment initiatives, samples will only be derived from their project areas. Using suggested locations limits the population to relevant sample areas.

Collection:

Soil samples were collected across four reaches: dominant, control, treated, and present. Dominant refers to a stand where salt cedar has crowded out almost, if not all of, the native vegetation. Control does not have any salt cedar. Treated refers to where Ecoculture has implemented chemical cut-stump treatments. These reaches may vary by phase year and subsequently represent different stages in the treatment process. The start year for a given area will be included in the data. Present includes areas where native biota is still established, but salt cedar exists to a minimal extent. The specific sites were determined in reference to the shapefiles provided by Ecoculture (see Figure A3). For each sample, an auger, a tool commonly referred to as an "earth drill," was used to reach a consistent sample depth of about six inches (see Figure C2). Excessive deposits of organic matter or large rocks were avoided when collecting samples. Each bag of soil was clearly labeled with an arbitrary sample number that was later used for consistent identification throughout the analysis process.

Texturing:

To measure the texture ~100 mL of water was combined with ~80 mL of prepared soil in a graduated cylinder. The graduated cylinder was inverted and shaken thoroughly to create a homogenous mixture. After settling for at least 48 hours, the particles were sorted by size into varying layers (see Figure C3). These are defined by sand, silt, and clay. Sand has the largest particle size and is therefore the most permeable. Clay, on the other hand, consists of fine particles with high water retention. Using heights of each layer divided by the height of the overall sample, the researcher was able to derive the texture composition by percent of a given sample. The provided percentages can then be interpreted using the soil texture triangle (see Figure A2). This metric was significant because the texture of a given sample can influence the readings from an electrical conductivity machine - the tool used to determine a salinity value. By accounting for texture, the results gave a truer indication of how salt cedar presence related to salinization. Early into collection, it was noted that large pebbles skewed texturing results by creating a disproportionate percentage of sand particles. To mitigate this, samples were filtered through the first layer of a soil sieve. This is a tool that acts as a filter for varying particle sizes. This prevented shells, rocks, and large deposits of organic matter from skewing readings. Some samples also had indistinguishable layers or took several extra days to adequately settle. In an attempt to remedy this, a small quantity of alum powder was added to a few of the samples that presented challenges. In the soil testing industry, alum powder is commonly leveraged as a solution to this because it has coagulant properties that helps particles settle in water (Alum, n.d.). There was an immediate distinction between samples with and without alum (see Figure C4). In samples with the additive, a clear layer pressed the soil downwards from the top. Although the change showed promising results in the beginning, it ultimately made the layers more difficult to observe. The results using this method were disregarded in exchange for their initial tests. In other words, none of the textures from the final dataset were derived with the addition of alum.

Salinity:

Electrical conductivity (EC) is a measure of the concentration of ions in a solution, taken by quantifying the conductivity passing through an EC machine. This metric is a known proxy for soil salinity. To measure, a 1:5 ratio of soil to distilled water was used. Specifically, 100 mL of distilled water was combined with 20 g of prepared soil in a disposable plastic cup. Measuring with an EC machine provided the $EC_{1:5}$, the electrical conductivity of a sample with a 1:5 ratio of soil to distilled water. Using distilled water was imperative to consistent results because of the large quantity of ions present in tap water. Each sample was measured three times to eliminate outliers. The collected soil samples all had moisture present. Initially, this was not accounted for and as a result there were random variations in the readings. To eliminate this unwanted variable, samples were dried out prior to measuring salinity (see Figure C1). Once the $EC_{1:5}$ was documented, it was multiplied by the factor corresponding to its texture to find the EC_E. EC_E refers to the salinity measured from a soil extract paste. Because this process is long and arduous, many labs opt for converting $EC_{1:5}$ readings into EC_E values. Due to the scope of this process, the research also followed this practice as opposed to a true soil extract salinity. By using a conversion equation (see Figure A1) that included the sand and clay percentage compositions, the results yielded values that could be applied to any soil condition. In other words, this provided a consistent scale for analysis across soil texture. All salinity measurements were collected in deciSiemens per meter (dS/m). This is the industry standard for quantifying soil salinity.

Analysis:

Analyzing the data required the use of ArcGIS online and Excel spreadsheets. Geospatial Information Systems (GIS) is a program that utilizes geographic information to visualize data and run complex analyses. Any field data was collected on ArcGIS field maps. This entailed recording a sample's reach, sample number, and any observations. The app was linked to a Bad Elf Flex Mini receiver that collected coordinate geospatial data. Throughout texture and salinity analyses, however, information was recorded on a comprehensive google spreadsheet. Every trial was noted in conjunction with a given sample's arbitrarily assigned sample number that corresponded to ArcGIS data. Aggregating the data from both platforms allowed the creation of geographic visualizations layered with Ecoculture's treatment phase shapefiles. By identifying averages, ranges, and standard deviations across all the reaches, charts and graphs were able to highlight trends and relationships. The final visuals incorporated data with a primary focus on how salt cedar extent corresponds to soil salinity.

Results

In total, 60 samples were analyzed across all four reaches. In each reach, five sites were identified, and at each site, three samples were collected. For each sample, a combination of qualitative and quantitative data was collected. Every sample includes information about its geographic location, salt cedar extent, treatment phase year (if applicable), texture, $EC_{1:5}$, EC_E, and observations throughout the process. There are also image files associated with each sample location that depict exactly where the sample was taken. Overall, 30 retests were performed due to shifts in methodology. Samples 1-21 had their salinity retested with the addition of the drying process to account for the moisture content skewing results. Also, samples 1-5 needed to be re-textured with filtering to avoid large aggregates. Samples 6-8 were retested with the addition of alum powder, but ultimately the initial data was maintained because the alum did not improve the process. The represented textures include sandy loam, loamy sand, clay loam, sandy clay, clay, silt loam, silt, and sand (see Figure B3). This variety means that salinity levels are less likely to be products of the soil they were found in. Leveraging this in conjunction with the conversion equation that included texture variation ensured consistent EC_E values. EC_E values ranged from 26.45 dS/m to 0.18 dS/m. There were 3 stark outliers in EC_E value when looking at site cohesion and 3 outliers when looking at reaches as a whole. The $EC_{1:5}$ was collected in 3 trials to minimize and identify outliers. These were averaged and used to calculate the EC_E. The data yielded comprehensive insights that help answer the research question upon further analysis.

Analysis

Upon layering the data and evaluating connections between information, there were emergent trends surrounding the results. For each reach, the average EC_E reading was derived along with its range and standard deviation. Standard deviation is important because it tells the average distance each reading had from the average. A lower standard deviation is preferred because it indicates that the readings had high consistency. The averages of all reaches were directly compared (see Figure B1). Samples from the dominant salt cedar reaches consistently had the highest EC_E levels, averaging at 6.85 dS/m. This is a stark difference compared to the average of 0.68 dS/m in sites with no salt cedar presence. The dominant reach of salt cedar saw the most varied EC_E readings with a range of 25.57 dS/m and standard deviation of 7.59 dS/m. The present reach however was comparatively consistent with a range of 1.35 dS/m and a standard deviation of 0.45 dS/m. This indicates that reach does affect the salinity of the soil. This directly addressed a key assumption established early in the research process: a relationship exists between soil salinity and salt cedar populations. To visualize the data effectively, ArcGIS was leveraged. This allowed for the combination of geospatial data with EC_E values and salt cedar reach (see Figure B4). Ultimately an amount and type analysis was run where the color of a point corresponded to the reach and the size indicated the salinity. The findings from this visualization aligned with the data derived from the spreadsheet. EC_E hotspots were consistently red and purple (dominant and treated reaches respectively). After understanding the data, both geospatially and using graphics derived from filtered spreadsheets, it became clear that there were consistent trends in the relationship between EC_E and the extent of salt cedar in a given plot. Furthermore, the analyses performed on the results indicate that the more concentrated the salt cedar population, the higher the salinity of the soil. The treatment reach exhibited the second highest salinity readings with an average of 3.11 dS/m. This indicates that treatment, although it does not entirely reverse the effects of salt cedar, significantly reduces the salinity to a level where only sensitive to moderately sensitive vegetation would be adversely affected; plants like willows and cottonwoods can still face damages at electrical conductivities around 3 dS/m (*Salinity*, 2007). Furthermore, this corroborates the trend observed by Hultine and his colleagues (2015). They noted how fremont cottonwoods still had suppressed microbial relationships post treatment - if the EC_E is still at risk levels for this particular plant, one could infer that the legacy effect would be more significant. Along with evaluating the general impacts of treatment on salinity, the exploration of how Ecoculture's treatment methods affect soil salinity also justifies focus on how the treatment phase year influences the EC_E (see Figure B2). It is important to note that this was not the primary independent variable, so there were not sufficient trials to concretely eliminate outliers. It is plausible that the samples taken from a specific year were not representative of all soil salinity throughout that phase year. From the collected data, there was no clear trend between time of treatment and resulting salinity. There were also several outliers that warrant examination.The dominant, control, and treated reaches each had an abnormally high reading. Samples 12, 13, and 21 (respectively) significantly exceeded the average EC_E without the skewed data point. While these were not removed from datasets for primary analysis, it is important to consider why these existed in the first place. Errors in collection could have stemmed from biased collection, contaminated equipment, or EC machine calibration. While the sites for sampling were predetermined based on Ecoculture's project shapefiles, the individual locations of the three trials were determined on site. It is possible that this left room for unintended biases, such as accessibility, that ultimately skewed some of the results. Another avenue for potential error relates to the equipment used in the field. The auger could have maintained particles from previous, saltier samples that in turn influenced the salinity readings.

This variable could have contributed to outliers or lack of clear correlations. Lastly, improper calibration of the EC machine could have created inconsistencies in the measured $EC_{1:5}$ readings. In turn, the EC_E values would have been varied depending on when the sample was assessed.

Conclusion

Following analysis, several conclusions can be derived from this causal comparative study. First, the data supports that salt cedar heavily impacts the surrounding soil, raising salinity to levels capable of damaging native vegetation. This is in line with other researchers' observations of the invasive plant. For example, the USDA (2014) describes how the plant is known to deteriorate a habitat's quality or functional integrity. When native vegetation is diminished by threats such as soil salinity, other processes begin to face challenges and the overall ecosystem resilience is lowered. Another key aim of experimentation was to identify and quantify a legacy effect in terms of soil salinity post treatment. This project was successful in demonstrating the existence of salt cedar legacy - treated sectors still exhibited salinization. However, without a clear correlation between treatment phase and EC_E, the data cannot support the claim that time since treatment is the driving factor of legacy intensity nor suggest that salinity will eventually return to normal levels. This ambiguity leaves room for future research intentionally exploring salinity over time in treated reaches of salt cedar. With more trials and samples, a trend could emerge and further inform restoration efforts along the Lower Salt River. While salinity still remained abnormally high, treatment did significantly reduce salinity compared to dominant reach readings. The reduction reiterates the viability of treatment programs that incorporate native vegetation. Programs, like Ecocculture's, seek to mitigate the negative impacts of salt cedar and cultivate new growth. The data from this experiment aligns with that initiative and quantifies the impact. Additionally, this project could inform restoration efforts by identifying the average salinity post-treatment. Because the soil still had EC_E's that could negatively impact sensitive and moderately sensitive vegetation, seeking out habitats with more tolerant vegetation (like mesquite) could improve restoration efforts. This is a key aim of any restoration project, as the ability or inability to foster restorative vegetation is often cited as a limiting factor (Jacobs & Sing, 2007). Ultimately this project sought to examine how Ecoculture's treatment procedure for salt cedar along the Lower Salt River affected soil salinity. Because of the narrow scope, the conclusions have limitations. The data consisted of a small population all with similar vegetation, climate, and chemistry. When considering the findings one must acknowledge that other treatment programs in different areas may demonstrate comparatively inconsistent trends. Because of this, an avenue for future research consists of conducting a similar study of a restoration program managed by a different company with different treatment methodologies. Expanding the sample size and variety would present more application to the conclusions beyond this specific population. Overall, the conclusions drawn from this research can provide insights about how to best approach salt cedar control going forward in the specific context of the Lower Salt River Restoration Project.

References

Alum Coagulant - an overview | ScienceDirect Topics. (n.d.). Www.sciencedirect.com. https://www.sciencedirect.com/topics/engineering/alum-coagulant

Gregory, S. V., Swanson, F. J., McKee, W. A., & Cummins, K. W. (1991). An Ecosystem Perspective of Riparian Zones. *BioScience*, *41*(8), 540–551. https://doi.org/10.2307/1311607

Hultine, K. R., Bean, D. W., Dudley, T. L., & Gehring, C. A. (2015). Species Introductions and Their Cascading Impacts on Biotic Interactions in Desert Riparian Ecosystems. *Integrative and Comparative Biology*, *55*(4), 587–601. https://doi.org/10.1093/icb/icv019

Jacobs, J., & Sing, S. (2007). *Ecology and Management of Saltcedar (Tamarix ramosissima, T. chinensis and T. ramosissima x T. chinensis hybrids)* . https://www.fs.usda.gov/rm/pubs_other/rmrs_2007_jacobs_j001.pdf

Kargas, G., Londra, P., & Sotirakoglou, K. (2022). The Effect of Soil Texture on the Conversion Factor of 1:5 Soil/Water Extract Electrical Conductivity (EC1:5) to Soil Saturated Paste Extract Electrical Conductivity (ECe). Water, 14(4), 642. https://doi.org/10.3390/w14040642

Naiman, R. J., Decamps, H., & Pollock, M. (1993). The Role of Riparian Corridors in Maintaining Regional Biodiversity. *Ecological Applications*, *3*(2), 209–212. https://doi.org/10.2307/1941822

Noss, R., Scott, M. J., & LaRoe, E. T. I. (1996). Endangered Ecosystems of the United States: A Preliminary Assessment of Loss and Degradation. *Ecological Restoration*, *14*(1), 95.1-95. https://doi.org/10.3368/er.14.1.95

Pyšek, P., Jarošík, V., Hulme, P. E., Pergl, J., Hejda, M., Schaffner, U., & Vilà, M. (2012). A global assessment of invasive plant impacts on resident species, communities and ecosystems: the interaction of impact measures, invading species' traits and environment. *Global Change Biology*, *18*(5), 1725–1737. https://doi.org/10.1111/j.1365-2486.2011.02636.x

Salinity Management Guide: Choose salt-tolerant plants. (2007, October 1). Watereuse.org. https://watereuse.org/salinity-management/cp/cp_7_table-2.html#source1_soil

Shrivastava, P., & Kumar, R. (2015). Soil salinity: A serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation. *Saudi Journal of Biological Sciences*, *22*(2), 123–131. https://doi.org/10.1016/j.sjbs.2014.12.001

Toy, R. (2021, July 13). *A legendary Arizona river is under threat*. Travel. https://www.nationalgeographic.com/travel/article/a-legendary-arizona-river-is-under-threat

USDA. (2014). *Field Guide for Managing Saltcedar in the Southwest*. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5410127.pdf

Zeng, Y., Zhao, C., Shi, F., Schneider, M., Lv, G., & Li, Y. (2020). Impact of groundwater depth and soil salinity on riparian plant diversity and distribution in an arid area of China. *Scientific Reports*, *10*(1). https://doi.org/10.1038/s41598-020-64045-w

Appendix A

Methodology Visuals and Resources

$$EC_{E} = \left(1.054 + \frac{283.4}{49.699 + 0.524 \cdot Clay\,\% - 0.339 \cdot Sand\,\%}\right) \cdot EC_{1:5}$$

Figure A1 - $EC_{1:5}$ to EC_{E} conversion

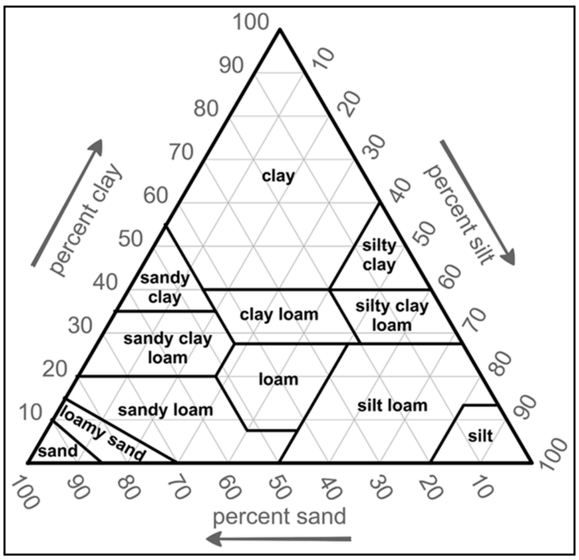

Figure A2 - Soil Texture Triangle

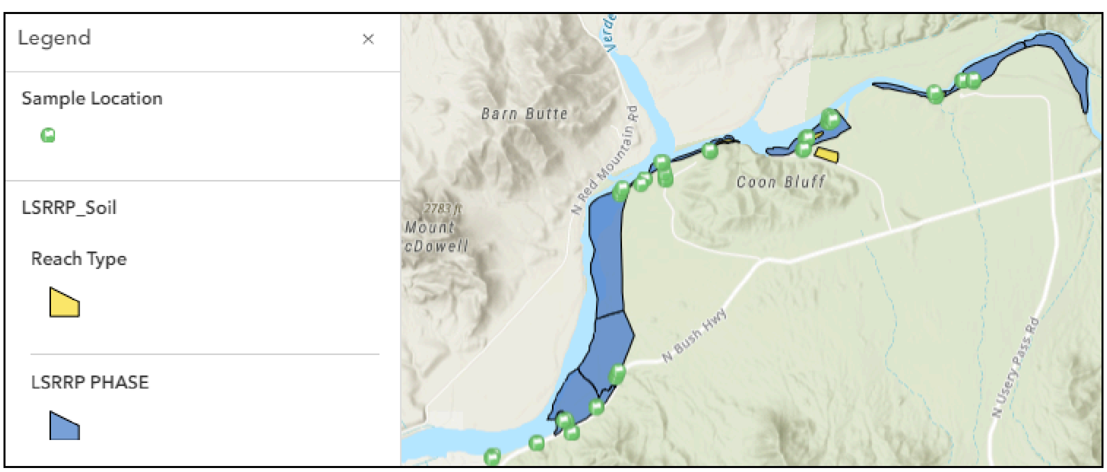

Figure A3 - Soil Sample Locations Layered with Ecoculture Shapefiles

Appendix B

Analyses

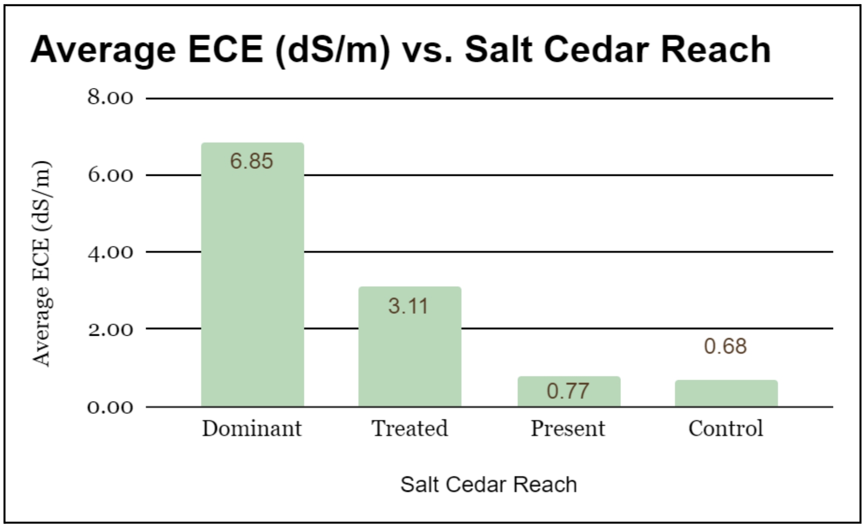

Figure B1 - EC_E by Salt Cedar Reach

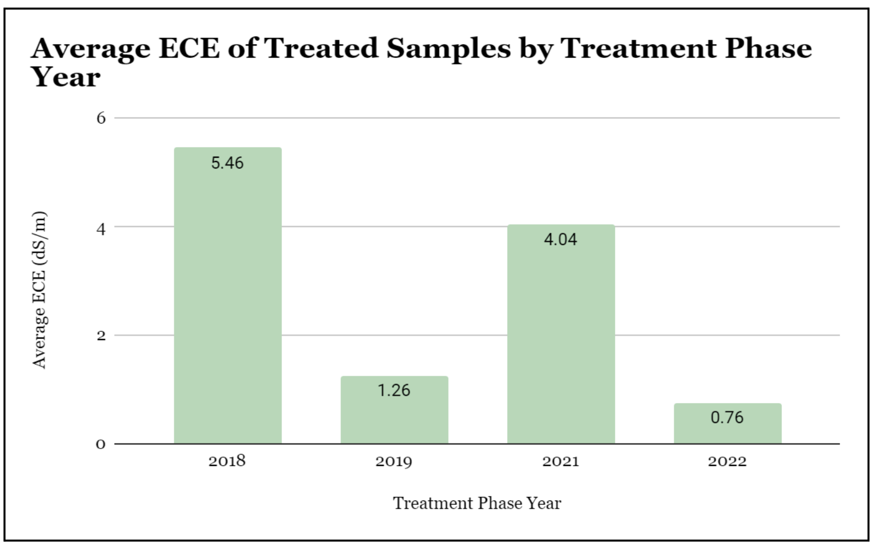

Figure B2 - EC_E by Treatment Phase Year

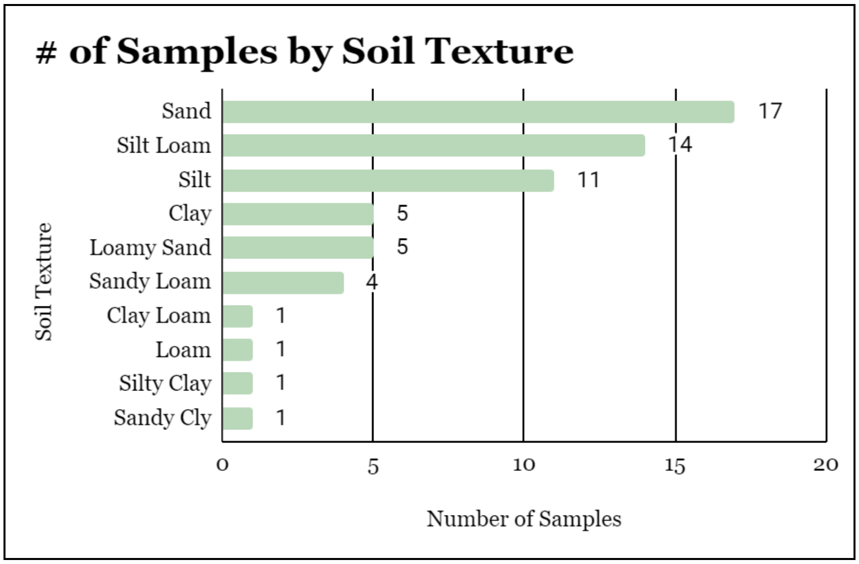

Figure B3 - # of Samples by Soil Texture

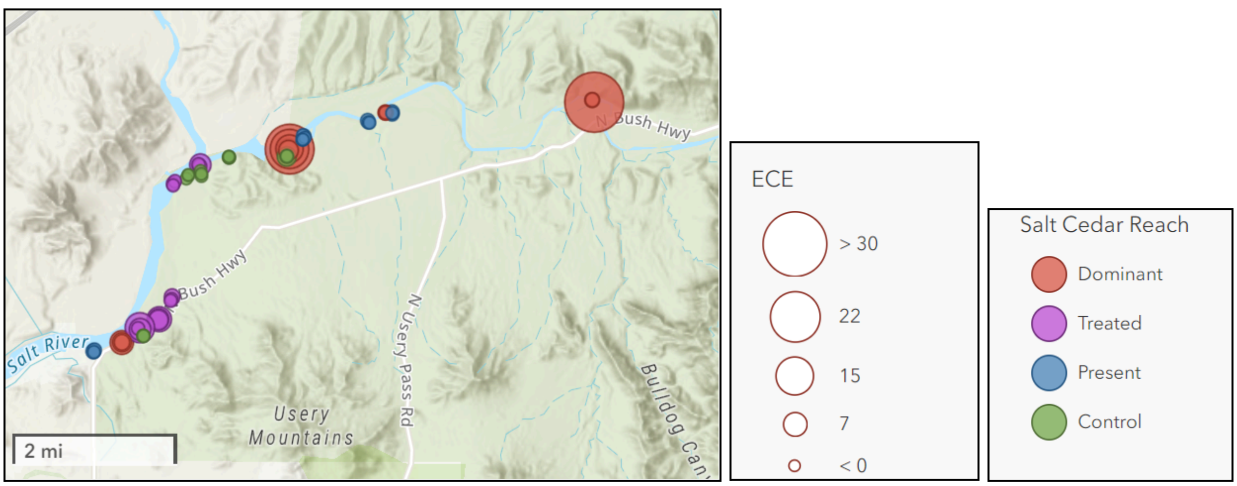

Figure B4 - Map Displaying EC_E and Salt Cedar Reach

Appendix C

Miscellaneous Pictures

Figure C1 - Soil Drying in Disposable Tins

Figure C2 - Auger used to Collect Samples

Figure C3 - Distinct Texture Layers

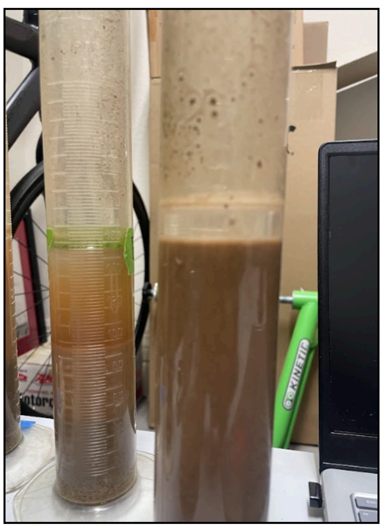

Figure C4 - Difference Between a Sample With (Right) and Without (Left) Alum