TOOLS TO ADVANCE ENVIRONMENTAL MONITORING, WETLAND RESTORATION AND EDUCATION IN THE DESERT SOUTHWEST

Anna Elisa Piña

Doctoral Program in Ecology and Evolutionary Biology

APPROVED:

Vanessa Lougheed, Ph.D., Chair

Elizabeth J. Walsh, Ph.D.

Jeffrey Olimpo, Ph.D.

Ivonne Santiago, Ph.D.

Stephen L. Crites, Jr., Ph.D.
Dean of the Graduate School

TOOLS TO ADVANCE ENVIRONMENTAL MONITORING, WETLAND RESTORATION AND EDUCATION IN THE DESERT SOUTHWEST

by

ANNA ELISA PIÑA

DISSERTATION

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

in Partial Fulfillment

of the Requirements

for the Degree of

DOCTOR OF PHILOSOPHY

Ecology and Evolutionary Biology Program

THE UNIVERSITY OF TEXAS AT EL PASO

August, 2022

ACKNOWLEDGEMENTS

This research was funded by STEMGrow (Dept of Education P031C160235), the USDA (2015-68007-23130) and the Research on STEM Education Course Development Fellowship (NSF-1826988). The National Park Service granted access to sample at Big Bend National Park (BIBE-2019-SCI-0030) and Guadalupe Mountains National Park (GUMO-2019-SCI-0019). I would like to thank Vanessa Lougheed for all her guidance and support through this project. Thank you to Elizabeth Walsh for site location suggestions, to Lixin Jin for processing water samples, and to John Sproul and all other wetland managers for allowing us to collect at their sites. Thank you to Enrique Garcia for help with making the map for Chapter 1. The wetlands project would not have been possible without the help from STEMGrow project managers Paul Hotchkin and Helen Geller and undergraduate research assistants: Viridiana Orona, Christy Adame, Jovannie Gomez, Bryan Yu, Alyssa Calderon, and Carlos Vargas. Rio Bosque Wetlands data for 2014 was collected by Jeanette Olivarez and Jessie Hampton.

The CURE project would not have been possible without the help and support from Paul Hotchkin, who let me commandeer his biology classes for over a year. Thank you to our peer leaders, Abigail Juarez and Laura Valdez, for their help every week with the in-person and virtual CUREs. Thank you to Jeffrey Olimpo for all his guidance thought the duration of this project. Special thanks to Ivonne Santiago, Miguel Velez-Reyes, Jeff Sivils, Harry Meeuwsen, and the Hispanic-Alliance for the Graduate Education and the Professoriate Fellowship for providing funding and mentorship that greatly enhanced the quality of the CURE project. This study received approval from the Institutional Review Board at the University of Texas at El Paso (IRB protocol #1552171-4) and the Dean of Architecture, Art, Math & Science of El Paso Community College, Dr. Carlos A.

Amaya. Thank you to the members of the Aquatic Ecology Lab and The Biology, Environmental, and Engineering Graduate Student Organization for your friendship and support.

Special thanks to volunteer field assistant, Emmanuel Jacquez.

ABSTRACT

The relatively rare freshwater ecosystems in the southwestern United States serve as biodiversity hotspots, yet they are among the most threatened systems in the world due to human impacts and climate change. Despite their importance to this arid landscape, the aquatic communities of desert wetlands remain relatively understudied. To restore and create new wetland habitats, effluent is becoming a more commonly used water source for these habitats. However, the effects of byproducts within the treated wastewater on these unique systems have not been well studied. In this study, we aim to better understand the factors that drive water quality and macroinvertebrate community composition of wetlands of the US desert Southwest. In addition, we focused on a local, restored wetland (Rio Bosque Wetlands), to better understand how water quality and community assemblages change with the increased use of treated effluent as a water source. Finally, in an effort increase awareness of habitat conservation and restoration we created an ecology-based virtual CURE (vCURE) that was implemented to non-science majors attending El Paso Community College.

Water quality and macroinvertebrate data were collected over three years from 14 different wetland and riparian sites spanning across West Texas, New Mexico, and Arizona. Results indicated that salinity related variables such as chloride, sulfate, and conductivity were the greatest drivers of environmental variance. Subsequently, nutrients were shown to have the greatest impact on macroinvertebrate communities with wetlands receiving treated wastewater showing a more uneven distribution of functional feeding groups (sites dominated by filter feeders) and lower Simpson Index scores. Increased salinity levels were also shown to correlate with lower Simpson Index scores thus, a decline in macroinvertebrate diversity and evenness.

To track the restoration of the Rio Bosque Wetlands, data collected in 2014, before a change in water regime, and data collected after (2016-2019) was used to determine differences in water quality and macroinvertebrate communities. The increased water inputs during the growing season in 2016-2019, established more permanent bodies of water which affected macroinvertebrate communities by allowing taxa with limited dispersal abilities time to build larger populations. Differences in assemblages within the park were also heavily influenced by the increased nutrients associated with effluent water. Overall, Rio Bosque Wetlands is displaying succession patterns similar to those of other, more established desert wetlands flooded with treated effluent water, with a growing community of filter feeders (Chapter 1). As a result, it is suggested that managers of these valuable created aquatic habitats try to find less nutrient-rich water sources, such as groundwater, to enhance the water quality in their sites. With reduced nutrient levels, we would expect to see an increased in sensitive taxa, predators, and collector-gatherers, among others. Though the macroinvertebrate community in created or restored sites, may not resemble those of a natural site due to the use of treated effluent water, these systems provide much needed habitat for aquatic flora and fauna within the desert landscape.

While the scientific community largely recognizes the importance the role of ecology plays in habitat preservation and combating the effects of climate change, much of the general population do not. To increase public understanding of preservation efforts for desert wetlands and other at-risk ecosystems, science literacy skills must increase within the community. Course-based Undergraduate Research Experiences (CUREs) have been used to improve science literacy and attitudes for large groups of students. In 2020 the COVID-19 pandemic and stay-at-home orders forced many college courses to switch to virtual learning which led me to create an ecology-based virtual CURE (vCURE). With the Undergraduate Research Student Self-Assessment (URSSA)

and the Test of Science Literacy Skills (TOSLS), we investigated the effects of participation in a vCURE on the science literacy skills, attitudes, and perceived gains of non-science majors and El Paso Community College. Our results showed that students were able to improve their overall TOSLS scores and increase their confidence levels in several general science and research related activities. In open ended responses, students felt that the course helped them improve skills that would be beneficial to them in the future, including communication, collaboration, and critical thinking. This shows that non-science majors can still benefit from CUREs though they do not intend to pursue a science related career. This CURE model can be modified to enhance students' knowledge of habitat conservation by creating an in-person wetland-themed CURE to further track the restoration of the Rio Bosque Wetlands.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Around the world, freshwater ecosystems are under continuous threat due to anthropogenic pressures and altered weather patterns due to climate change (Robert T. Brooks 2009; Mekonnen and Hoekstra 2020; Woodward, Perkins, and Brown 2010a) (Robert T. Brooks 2009; Mekonnen and Hoekstra 2020; Woodward, Perkins, and Brown 2010b). These changes have led to a decline in aquatic biodiversity that exceeding that of terrestrial systems due to the increasing demand for fresh water (Vörösmarty et al. 2010). Over time, changes to hydrological regimes will likely impact the flora and fauna of these systems due to fluctuating timing and magnitude of wetland inundation (Pitchford et al. 2012). With these challenges expected to become more severe, this becomes extremely problematic for wetland ecosystems, which rely on water availability to maintain basic wetland functions (Strayer and Dudgeon 2010).

Wetlands of the Desert Southwest

The southwest United States, though normally arid, has seen a drastic increase in drought conditions over the past 10 years due to changes in precipitation patterns (McKinnon, Poppick, and Simpson 2021; Overpeck and Udall 2020). In addition, rising temperatures pose a threat to these unique habitats by increasing evapotranspiration rates and the potential for prolonged megadrought conditions (Overpeck and Udall 2020; Strzepek et al. 2010; USDA Forest Service 2010).

The freshwater ecosystems in the arid southwestern United States serve as biodiversity hotspots, supporting a disproportionately high share of landscape diversity (Dinerstein et al. 2001; Stanislawczyk et al. 2018). These systems function as refugia for aquatic taxa such as macroinvertebrates (Griffis-kyle et al. 2019; Moorhead, Hall, and Willig 1998), fishes (Zengel and Glenn 1996), and macrophytes (Karpiscak et al. 2001). They also serve as nesting habitat for

migratory birds (García et al. 2017). Recent studies have begun to highlight the novel communities within these habitats, emphasizing the presence of endemic and cryptic taxa (Griffis-kyle et al. 2019; Seidel, Lang, and Berg 2009; Stanislawczyk et al. 2018). Recently, there has been a push to better understand these assemblages and what drive this community composition (Bogan et al. 2014; Colombetti et al. 2020; Esposito 2012; Sei, Lang, and Berg 2009; Stanislawczyk et al. 2018). For example, Stanislawczyk et al. 2018, found that geographic distance between desert springs was a better predictor of macroinvertebrate community composition than abiotic parameters, likely due to isolation and limited dispersal between sites. These results are consistent with similar studies in desert springs in the Mojave Desert (Sada, Fleishman, and Murphy 2005).

While the threat to these arid wetlands has been understood since the 1980's (Hendrickson and Minckley 1985), they remain among the most understudied systems in the world (Nieto et al. 2017). For example, there are 15,000 springs in the southwest United States that have been identified and are being monitored, with nearly none having recorded historical data (USGS, 2018).

The biodiversity within these freshwater systems is especially vulnerable to climate change due to their relative isolation and fragmentation, leaving species with limited opportunity to disperse (Davis et al. 2013; Erwin 2009). Along with climate change, urban wetlands of the southwest face human related disturbances such as agriculture run off, vegetation removal, changes to water levels and drainage patterns; all of which contribute to their vulnerability. Recently, there has been a growing interest in restoring or creating freshwater habitats with the use of effluent water from wastewater treatment plants (Hamdhani, Eppehimer, and Bogan 2020; Hsu et al. 2011; O'Geen et al. 2010; Rodriguez and Lougheed 2010). Though this method usually provides a constant water source for these systems, the long-term effects of exposure to the high

nutrient levels in the effluent water remains to be seen (B. W. Brooks, Riley, and Taylor 2006; Hamdhani, Eppehimer, and Bogan 2020).

Assessing created or restored wetlands

Along with this push for restoration comes the need for ways to track the restoration and the health of these wetlands. Many methods have been developed and used to track the restoration of created or restored wetlands. There have are several assessments using wetland plants including monitoring the abundance of native species (Adamus and Brandt 1990; Taddeo and Dronova 2018) in addition to plant biomass and tolerance to disturbance (Lopez and Fennessy 2002; Zhao et al. 2016). Wetland fauna have also been used as indicators of restoration. For example, the abundance of small fish, crustaceans and wading birds have been used as measures of healthy food web relationships in restored areas of the Everglades (Trexler and Goss 2009). Diversity indices are also commonly used as indicators of restoration, with most studies only focusing on the assemblages of one group of organisms: typically plants or vertebrates for conservation projects (Ruiz-Jaen and Aide 2005; Sebastián-González and Green 2016). Finally, ecological processes, such as nutrient cycling, are used less often than vegetation or diversity indices because they are usually slower to recover from disturbance and require multiple measurements over time (Ruiz-Jaen and Aide 2005).

Some studies have attempted to identify the macroinvertebrate metrics that would be best used for tracking wetland restoration but they have proven to be inconclusive at indicating success (Marchetti, Garr, and Smith 2010; Meyer and Whiles 2008; Ruhí et al. 2012). Others have shown that macroinvertebrate diversity (Simpson Diversity Index and Invertebrate Community Index) of created wetlands was significantly lower when compared to natural wetlands (Acharyya and Mitsch 2000; Spieles and Mitsch 2000; Swartz et al. 2019) and that dissolved oxygen and specific

conductivity were the best predictors for species diversity (Spieles and Mitsch 2000). In another study focusing on wastewater ponds, drivers of community composition were identified as pH, vegetation structure, and pollution levels (Becerra et al. 2009). When comparing created, impacted and reference wetlands, it was determined that the amount of vegetation had the greatest influence on macroinvertebrate taxonomic richness (Swartz et al. 2019). While these few studies give some insight to what may drive community composition, none of them were conducted in desert wetlands, where water characteristics are very different, especially in salinity and hydroperiod, and where different "core" assemblages of macroinvertebrates may be found (Ruhí, Batzer, and Ruhí 2013). Therefore, it cannot be assumed that they will respond the same way to restoration efforts.

Aquatic macroinvertebrates as bioindicators

While macroinvertebrates are not often used as indicators of wetland restoration, they have, for decades, been used as a means of assessing water quality within freshwater systems due to the fact that they are in constant contact with water and sediment where many pollutants accumulate (Mandaville 2002). In past studies, macroinvertebrates communities have been used as biological indicators of heavy metals (Ordonez et al. 2011), nutrient enrichment (Cortelezzi et al. 2015; Søndergaard and Jeppesen 2007), land use (Anderson and Vondracek 1999; Sada, Fleishman, and Murphy 2005) vegetation cover (Death and Collier 2010; Lawrence et al. 2016), salinity (Dunlop et al. 2008; Sowa, Krodkiewska, and Halabowski 2020), and overall biomonitoring of freshwater habitats (Cairns and Pratt 1993; Johnson, Wiederholm, and Rosenberg 1993; López-López and Sedeño-Díaz 2015; Lougheed et al. 2007; Serrano Balderas et al. 2016; R. C. Sharma and Rawat 2009).

Many biological indices have been developed as a measure of organic and nutrient pollution within freshwater systems based on the presence or absence of tolerance and/or sensitive species. For example, the Hilsenhoff Biotic Index assigns pollution tolerance levels to macroinvertebrate families. The degree of organic pollution can then be determined based on the average tolerance level of the macroinvertebrates collected from that site (Hilsenhoff 1987). Another reliable biotic index used to assess water quality is the EPT Index, which meassures the richness of the most sensitive macroinvertebrate groups: Ephemeroptera (mayflies), Plecoptera (stoneflies) and Tricoptera (caddisflies) (Lenat 2016). The absence or presence of these orders can then be used to evaluate the quality of the water (Lenat and Science 1988). Other available indices that may be used include the Simpson Diversity Index as well as the Invertebrate Community Index (Spieles and Mitsch 2000). Several studies have also used macroinvertebrate species composition within multivariate statistical analysis to help understand patterns in communities composition along environmental gradients (Gleason and Rooney 2018; Lougheed et al. 2008; Moreno, Angeler, and De las Heras 2010; Zimmer, Hanson, and Butler 2011).

While many of these indices and metrics have proven to be reliable in wetlands and streams in temperate regions, it is unknown whether macroinverbreate assemblages in desert wetlands respond to distubance in the same way. This comes as a recent study has higlighted disparities of using the same indices across differing systems (Mazor et al. 2016).

Course-based Undergraduate Research Experiences (CURE)

While the scientific community largely recognizes the importance that ecology plays in habitat preservation and combating the effects of climate change, many outside of this group do not. To intensify preservation efforts for desert wetlands and other at-risk ecosystems, we must increase science literacy skills within the community. One way to better increase science literacy

is to have students conduct meaningful research at the undergraduate level (Sadler et al. 2010). While having all students conduct research at some point in their academic careers is ideal, it is not often feasible due to limited undergraduate research positions available (Desai et al. 2008). These opportunities are often very competitive and the vast majority of students at four year universities will not be able to obtain a research position; this number is even less at the community college level (Auchincloss et al. 2014; Bangera and Brownell 2014; Kloser et al. 2013; Weaver, Russell, and Wink 2008).

One method of overcoming the lack of research positions available to students is with a Course-based Undergraduate Research Experience (CURE). A CURE typically occurs in the lab portion of science course where the whole class is involved in addressing a research topic (Auchincloss et al. 2014). Over the course of the semester, students will design and implement their own research projects with the result being a poster they can present to the class, or even at conferences. Since CUREs are integrated into the course, students who may typically not have the opportunity to conduct research through internships will gain the relevant experience. Differing from inquiry projects, CUREs increase the value of science communication and literacy as students will be required to read and cite research articles along with having to present a research poster as the final assessment (Dolan 2016). CUREs have been shown to be useful tools for improving science literacy and attitudes for large groups of students (Auchincloss et al. 2014; Dolan 2016) though students a hands-on and immersive experiences.

CUREs serve as a way to give research opportunities to more students, this in turn also helps to break down some of the barriers these students may face, thus increasing inclusivity (Bangera and Brownell 2014). Reasons for this loss include: lack of awareness of existing research opportunities and their benefits, differences in cultural norms, and financial or person barriers

(Bangera and Brownell 2014). This loss of retention is increased in students who attend non-4 year universities at the beginning of their undergraduate careers. With approximately 34% of students nationwide beginning their higher education careers at community colleges, this means a large proportion of students fall through the cracks every year (Community College Research Center, 2017).

Moreover, a high percentage of these students are coming from lower socioeconomic and underrepresented populations. In many community colleges there are little to no opportunities for their students to participate in undergraduate research; many of their students then transfer to 4 year universities with no research experience and no knowledge of how find or apply for research programs (Bangera and Brownell 2014). This becomes problematic as independent research is quickly becoming an unofficial prerequisite for admission to graduate school.

In 2020 the COVID-19 pandemic and stay-at-home orders forced many college courses to switch to virtual learning. CURE courses, which are recognized for their hands on activities student interactions, were now moved to an online setting. This major change, however, challenged educators to develop unique and innovated virtual CURES (vCURE) that still engaged students and allowed for hands on activities in a safe manner (Corson et al. 2021; Majka et al. 2021). Many developed what is now known as "CURE in a box" where students receive all the supplies necessary to conduct laboratory activities at home (Bennett et al. 2021). While this work great with more lab-based microbiology courses, they are not ideal for ecology-themed CUREs. While ecology-themed CUREs our outnumbered by their microbiology counterparts, previous research highlights the benefits of these types of courses (Kloser et al. 2013).

Goals and Objectives

In this study I aimed to fill gaps in knowledge regarding the drivers of macroinvertebrate community composition within desert wetlands of the southwest United States. In addition, we focused on a local, recently restored wetland, to better understand how water quality and community compositions change with the addition effluent water as a water source. Finally, I created an ecology-based virtual CURE (vCURE) that was implemented to non-science majors and El Paso Community College. This study will address the following objectives and underlying questions:

1. Identify drivers of macroinvertebrate community composition in wetlands of the desert Southwest of varying water sources [Chapter 1].
2. Determine how water quality and macroinvertebrate community composition in the Rio Bosque Wetlands have responded to wetland restoration efforts [Chapter 2].
3. Implement and investigate what effects participation in a virtual ecology- themed Course-based Undergraduate Experience had on the science literacy skills, attitudes, and perceived gains on non-science majors at a community college [Chapter 3].

This information can be used to better understand the succession that these unique systems go through during the restoration process. In turn, we sought to highlight key factors that could lead to better management practices of restored or created wetlands. With the vCURE we hope to adapt it for future use to better increase positive attitudes towards science, improve science literacy skills and create greater accessibility of research experiences for non-traditional students.

CHAPTER 1: ARE NUTRIENTS OR SALINITY THE DRIVERS OF MACROINVERTEBRATE COMMUNITY COMPOSITION IN WETLANDS OF THE DESERT SOUTHWEST?

1.1 INTRODUCTION AND BACKGROUND

The loss of global biodiversity is occurring at an exceedingly rapid rate due to climate change and overexploitation by humans (Dawson et al. 2011). While terrestrial ecosystems are often in the spotlight, aquatic ecosystems surpass their rate of loss of biodiversity due to declines in water quality, changes in nutrient availability and increasing temperatures (Association of State Wetland Managers 2015; Van De Waal et al. 2010; Xi et al. 2021). Arid region wetlands are especially vulnerable due to altered precipitation patterns related to climate change and declining groundwater flow as a result of overuse (Burkett and Kusler 2000; Taylor et al. 2013; Richey et al. 2015). As biodiversity hotspots, these oases are habitat for many organisms and provide critical habitat connectivity within the desert landscape (Dinerstein et al. 2001; Bogan et al. 2014; Drake et al. 2017). While freshwater habitats are known to support ~10% of all species, including many endangered and endemic species, arid region wetland ecosystems worldwide remain understudied and under-recognized when it comes to wetland ecology and conservation (Hershler and Liu 2010; Minckley et al. 2013; Murphy et al. 2013; Nieto et al. 2017; Stanislawczyk et al. 2018; Strayer and Dudgeon 2010; Walsh et al. 2009). Due to the rapid loss of habitat, there has been a recent push to protect and restore these rare freshwater ecosystems.

In the southwest United States, many wetlands have been restored or created to replace those wetlands that have been lost. Some wetland sites use the delivery of wastewater to mitigate or restore areas that were previously lost or degraded due to river channelization or agricultural use

(O'Geen et al. 2010; Rodriguez and Lougheed 2010). These sites create new habitats for migrating birds and aquatic organisms and well as areas of cultural value such as city parks (Andrade et al. 2018; Hamdhani et al. 2020; Bogan et al. 2020). These habitats are often used to further purify effluent water through the uptake of nutrients (i.e., nitrogen and phosphorus) and contaminants by wetland macrophytes and microalgae before replenishing groundwater sources (Whitton et al. 2016; Matamoros et al. 2017; Zhuang et al. 2019). While studies have shown these wetlands to be effective at reducing excess nutrients and contaminants from wastewater, the initial presence of these byproducts may have lasting effects on freshwater biota (R. T. Brooks 2000). In some non-arid created wetlands, increased nutrients cause shifts in community composition with an increase in pollution-tolerant macroinvertebrate taxa (Pinto et al. 2014). However, due to variables relatively unique to arid regions (i.e., extreme heat, irregular and rare precipitation), it is unknown if macroinvertebrates in arid wastewater wetlands respond the same way as those in non-arid regions.

In freshwater ecosystems, macroinvertebrates have historically been used as indicators of water quality and wetland health (Hilsenhoff 1987; Mandaville 2002). As bioindicators, aquatic macroinvertebrates serve as a low-cost and useful tool for monitoring wetland health and function due to their constant contact with water and sediment (Hilsenhoff 1987; Cairns and Pratt 1993; Bartell 2006; Siddig et al. 2016; McIntosh et al. 2019). By monitoring the abundance, diversity, and reproductive success of these organisms we can determine habitat response to change or disturbance (Foote and Rice Hornung 2005; Siddig et al. 2016; Wu et al. 2017). While these biotic indices are easily applied to non-arid region habitats, it should not be assumed that macroinvertebrates in arid habitats will respond the same way to environmental stressors. Recent