



Department of Watershed Sciences

Spring 2021

Graduate Student

Research Symposium



Friday, April 9, 2021

Huntsman Hall 322

8:30 am – 3:00 pm

Utah State University
Quinney College of Natural Resources
Department of Watershed Sciences
Graduate Student
Research Symposium

April 9, 2021

Welcome to the Department of Watershed Sciences Graduate Research Symposium. This symposium provides an opportunity for our graduate students to present ideas about their thesis/dissertation research and to receive feedback regarding their plans. Your comments and insights are welcome and expected.

Six Ph.D. students will give their biannual update at the departmental seminar prior to the symposium. At the symposium, we will hear from an additional thirteen M.S. and eight Ph.D. students. Their presentations are a sample of the diversity of water resource, conservation, and ecosystem science issues that faculty, students, and research associates in the Department of Watershed Sciences explore.

**4:00pm: Spring Kickball Game (Graduate Students vs. Faculty/Staff)
on the Aggie Legacy Field.**

6:00pm: Social at Peter Wilcock's house (1624 Sunset Dr., Logan)



WATS Graduate Student Research Symposium Schedule

All presentations will be given live in Hunstman Hall 322, except those indicated by an (R), which will be presented remotely.

8:30	Welcome: Dr. Patrick Belmont	11:30	Melissa Cobo-Arias, MS in Watershed Science <i>Major Advisor: Dr. Soren Brothers</i>
8:45	Cat McClure, Ph.D. in Ecology (R) <i>Major Advisor: Dr. Edward Hammill</i>	11:45	Macy Gustavus, MS in Watershed Science <i>Major Advisor: Dr. Janice Brahney</i>
9:00	Jiahao Wen, Ph.D. in Ecology <i>Major Advisor: Dr. Janice Brahney</i>	12:00	Lunch
9:20	Jes Braun, MS in Ecology <i>Major Advisor: Dr. Karin Kettenring</i>	12:45	Molly Blakowski, Ph.D. in Watershed Science <i>Major Advisor: Dr. Janice Brahney</i>
9:35	Kate Sinnott, MS in Ecology <i>Major Advisor: Dr. Karin Kettenring</i>	1:00	Dale Fonken, MS in Watershed Science <i>Major Advisors: Drs. Mary Conner (WILD) & Timothy Walsworth</i>
9:50	Christina Morrisett, Ph.D. in Watershed Science <i>Major Advisor: Dr. Sarah Null (Ph.D. Update)</i>	1:15	Martinique Chavez, MS in Ecology (R) <i>Major Advisor: Dr. Phaedra Budy</i>
10:05	Greg Goodrum, Ph.D. in Watershed Science <i>Major Advisor: Dr. Sarah Null</i>	1:30	Tansy Remiszewski, MS in Ecology (R) <i>Major Advisor: Dr. Phaedra Budy</i>
10:20	Sara Wall, MS in Watershed Science <i>Major Advisor: Dr. Patrick Belmont</i>	1:45	Katy Gardner, Ph.D. in Watershed Science <i>Major Advisor: Dr. Charles Hawkins</i>
10:35	Break	2:00	Manny May, MS in Fisheries Biology <i>Major Advisor: Dr. Timothy Walsworth</i>
10:45	Denny Haynes, MS in Watershed Science <i>Major Advisor: Dr. Carl Saunders</i>	2:15	Coryna Hebert, MS in Ecology (R) <i>Major Advisor: Dr. Karin Kettenring</i>
11:00	Alec Arditti, Ph.D. in Watershed Science <i>Major Advisor: Dr. Patrick Belmont</i>	2:30	Rachel Watts, MS in Watershed Science (R) <i>Major Advisor: Dr. Janice Brahney</i>
11:15	Christy Leonard, Ph.D. in Watershed Science <i>Major Advisor: Dr. Jack Schmidt (Ph.D. Update)</i>	2:45	Gordon Gianniny, MS in Watershed Science <i>Major Advisor: Dr. Janice Brahney</i>



Abstracts: WATS Symposium

Cat McClure, Ph.D. in Ecology

Major Advisor: Dr. Edward Hammill

Species interactions scale up to influence community structure in microscopic aquatic communities

Species interactions structure ecological communities through stabilizing and destabilizing mechanisms. These interactions can include competition, predator-prey interactions, and mutualism. Although species interactions are known to influence community structure, less is known about how these different types of interactions fluctuate along environmental gradients within a micro-community. My proposed research will investigate the influence of top-down versus bottom-up controls on community structure by comparing the strength of predator-prey interactions to the strength of conspecific competition. Many prey species have been observed to induce morphological and behavioral defenses under the risk of predation, which may alter the strength of species interactions and overall community structure. However, the magnitude of defense expression may depend on the density of predators, and conspecifics. Specifically, I will measure the length and width of the protozoa *Paramecium aurelia* under a gradient of both predator (flatworm) and nutrient concentrations. Greater width confers a morphological protection to *P. aurelia* as their gape-limited predators are unable to consume prey larger than their mouths. Additionally, movement data will be recorded in order to investigate changes in movement rates in response to increased predator and nutrient concentrations. Movement rates may drop in the presence of predators to reduce encounter rates, but incur a cost in terms of reduced foraging rates. By investigating the morphological and behavioral responses of *P. aurelia* under changing predator and nutrient concentrations, we can better understand 1) how conspecific competition and predation interact and influence the inducible defense mechanisms of protists, 2) evaluate a potential tradeoff point between response to predation and response to conspecific competition, and 3) begin to better understand the role of bottom-up versus top-down controls on the structure of ecological communities. An increased understanding of species interactions under a controlled setting will provide increased awareness of how ecological communities in natural environments might respond to changing biodiversity, species-loss, or non-native species expansion.

Jiahao Wen, Ph.D. in Ecology

Major Advisor: Dr. Janice Brahney

Phosphorus bioavailability of dust and influences on the mountain ecosystems in the western US

Dust has the potential to transport limiting nutrients including phosphorus (P) and nitrogen (N) to remote mountain ecosystems, either in short term (waterbodies) or long term (mountain soils). A critical unknown is the bioavailability of P in dry dust deposition and to what extent these cross-system subsidies influence mountain ecosystems, especially biogeochemical cycling and biological processes. Global P deposition has increased by 1.4 times the preindustrial rate largely due to increased dust and biomass burning emissions. Yet, increased total P deposition doesn't indicate linear increased uptake by organisms due to varied P bioavailability and different ecosystem types. Mountain lakes tend to be sensitive to atmospheric deposition because of naturally oligotrophic status, simple food webs, and far from human disturbances. However, there are not studies to date experimentally testing how dust influenced mountain lakes chemistry, primary production, and community composition. Different lake types such as nutrient limitations and pH are able to influence short-term P release and uptake through direct desorption of particle surfaces and phosphatase hydrolysis of organic P from dust particles. In a long-term perspective, atmospheric P flux could play an important role over local geological weathering in mountain ecosystems. Thus, estimation of P inputs into mountain soils between atmospheric deposition and other sources will help to understand how dust influence terrestrial nutrient cycling. To fill these knowledge gaps, I will 1) use various techniques to describe P species and bioavailability across spatial and temporal scales including chemical extraction, optical microscope, ³¹P nuclear magnetic resonance (NMR), and algal bioassays. 2) conduct *in-situ* dust addition experiments in various mountain lakes based on chemistry and nutrient limitations to understand how lake water and phytoplankton community respond to dust deposition. 3) Using existing atmospheric data and a mass balance method to estimate the role of atmospheric P inputs to mountain ecosystems.

Jes Braun, MS in Ecology

Major Advisor: Dr. Karin Kettenring

Reestablishing lakeshore vegetation in a highly impacted system: a Utah Lake case study

Wetlands are important to society, yet over half the global wetland area has been lost due to drainage, filling, native vegetation removal, invasive species, and hydrologic alterations. Restoration of wetlands is critical to recover lost ecosystem functions and services. Reestablishing native plant communities that contribute to ecosystem functioning is an important part of this process. Lacustrine wetlands, particularly those in the semi-arid Intermountain West region of the U.S., have experienced extensive hydrological alterations. They have sustained substantial water diversions and are commonly utilized as reservoirs, resulting in extreme changes in water levels that impact lakeshore vegetation. One highly altered system is Utah Lake, the location of my proposed research, in central Utah, USA. Utah Lake has vastly fluctuating water levels, and in some places, high wave energy and a large fetch. These dynamic wetland conditions challenge land managers aiming to reestablish lakeshore vegetation, particularly after removal of invasive vegetation.

The goal of my research is to determine best practices for native plant community reestablishment in lacustrine wetlands. Specifically, I will: 1) evaluate the effectiveness of wave break structures and different planting/seeding approaches to dissipate wave energy and mimic plant self-facilitation processes, 2) determine the importance of planting elevation to mitigate the effects of unnaturally dynamic water levels, and 3) identify what plant species do well under these challenging revegetation conditions.

To address [question 1](#), I will establish experimental plots with and without wave break structures where I plant plugs (dispersed or clumped arrangement; single species plots of hardstem bulrush or saltgrass) or seed a diverse 15-species seed mix (moderate or high density). To address [question 2](#), I will seed/plant at the land-water interface in late spring and again at the water line a month later once the water has likely receded. To address [question 3](#), I will evaluate which species in the seed mix do well across the different treatments. I will determine if they differ substantially in functional traits likely important under high wave energy/fetch (e.g., robust root/rhizome system) or dynamic water levels (e.g., broad hydrologic tolerance). This experiment will be conducted at two sites on the north shore of Utah Lake. All treatment combinations will be replicated 5 times. I will track plant performance over two years with mid-summer survival and end-of-season percent cover. I will also track soil moisture/water depth and wave energy monthly throughout the growing season. My research results will inform land managers, landowners, and restoration practitioners interested in best practices for revegetation of lacustrine wetlands in highly impacted systems.

Kate Sinnott, MS in Ecology

Major Advisor: Dr. Karin Kettenring

Improving establishment and invasion resistance in the restoration of aquatic plant communities

Aquatic plants play a major role in wetland ecosystem functioning through their effects on hydrologic regime, sedimentation, nutrient cycling, and habitat for aquatic organisms. However, anthropogenic activities such as species introduction, pollution, and land conversion have caused a global decline in aquatic plant density and diversity. Ecological restoration of aquatic plant communities may reestablish ecosystem functioning, but research on best practices for freshwater plant community restoration remains sparse and inconclusive. Currently practiced planting methods show extreme variability in establishment and are often not scalable due to material cost, time, or safety of planting conditions. Biotic interactions that may inform species choices for aquatic plant restoration are also poorly understood, particularly in sites that may be impacted by the presence of non-native plant invaders. To address these knowledge gaps, the objectives of this project are to 1) investigate planting methods that result in higher establishment of aquatic plantings, 2) expand techniques associated with scalability of aquatic plant revegetation, and 3) understand how species richness and identity impact invasion resistance in aquatic plant restorations. I will address these objectives with field and mesocosm experiments, where I will evaluate establishment across planting methods for both rooted and unrooted macrophyte species. Emphasis will be placed on testing methods in the field that may support conspecific facilitation, carp-resistance, and reduction of the time and cost needed for planting. I will also evaluate the effects of species richness and identity on the establishment of two non-native plant invaders (*Myriophyllum spicatum* and *Potamogeton crispus*) in greenhouse mesocosms across four native species and four levels of species richness. The results of my study will aid aquatic plant restoration by identifying successful and scalable macrophyte revegetation techniques and informing species richness and identity choices.

Christina Morrisett, Ph.D. in Watershed Science

Major Advisor: Dr. Sarah Null

Optimizing water resource management in the Henry's Fork watershed: Using and assessing a collaborative modeling approach

Water is a limited resource and collaborative water resource management is difficult to attain. In Idaho's Henry's Fork Watershed, a collaborative management group works to balance the needs of multiple water users, while meeting the constraints for storing and delivering water for irrigation. This group considers maximizing end-of-water-year reservoir storage an optimal strategy for providing the flexibility to meet various stakeholder interests and resiliency to future water supply uncertainty. The creation of a watershed-scale optimization model that considers current and future water availability and the needs of multiple water users to suggest a management approach—and is also built in collaboration with water managers—will serve basin needs for precision and multi-use water management. Christina will present 1) her plan for collaboratively building the optimization model and 2) the “toy” model she has created to guide the conversation.

Greg Goodrum, Ph.D. in Watershed Science

Major Advisor: Dr. Sarah Null

Robust aquatic habitat representations for conservation and water resources decision-making in the Bear River watershed

Rivers provide benefits for people and sustain aquatic ecosystems, and these water uses often conflict. Systems modeling analyzes tradeoffs between human and environmental objectives. Yet limited data and uncertain species-habitat relationships have traditionally made environmental objectives and aquatic habitats difficult to represent in systems models. My research will test alternative aquatic habitat representations in water resources systems models of the Bear River watershed to evaluate how uncertainty in habitat representation and environmental thresholds changes water management decisions. The objectives of my dissertation research are to: (1) develop a multi-objective hydro-economic-environmental optimization model for the Bear River considering human and environmental water demands, which evaluates alternative water management strategies including proposed reservoirs, existing reservoir re-operation, conservation, and water banking to identify promising water management solutions and quantify tradeoffs among water uses; (2) quantify uncertainty in my model by using robust decision-making analysis to identify when uncertain aquatic habitat representation causes water management decisions to change; (3) quantify accuracy and uncertainty of instream barrier passability for migratory fish species to improve aquatic habitat connectivity estimates; and (4) incorporate non-native species into existing habitat suitability models and evaluate where and when non-native species overlap with managed native species like Bonneville Cutthroat Trout and Bluehead Sucker. These objectives will enlarge solution space in water resources system modeling, enable stable decision-making with uncertain environmental conditions, and help inform conservation planning and water resources management in the Bear River watershed.

Sara Wall, MS in Watershed Science

Major Advisor: Dr. Patrick Belmont

Controls on post-fire debris flow grain size distributions and volumes in the Intermountain West

Post-fire debris flows (PFDF) represent one of the most destructive and potentially hazardous consequences associated with increasing wildfire severity. While the abundance of literature has explored the initiation processes and generation of PFDFs, investigations into their downstream impacts are limited. Modeling frameworks have begun to investigate the downstream impacts of post-fire erosion by predicting where PFDF sediment is generated post-wildfire, how much of that sediment is delivered to a stream channel, and how that pulse of sediment propagates downstream through the river network. While most inputs to such modeling frameworks are available through open source datasets, a significant gap still exists regarding the grain size distributions (GSD) of PFDFs and the factors influencing these GSDs. This presents a major obstacle in developing watershed-scale wildfire risk assessment models, as GSD exerts a first-order control on the rates and modes of sediment transport through a river network. Additionally, while models exist to predict the volumes of sediment deposited by PFDFs, the most prominent volume-prediction model (Gartner et al., 2014) was calibrated using data from Southern California. We therefore have a limited understanding of how this model functions in other regions. We have compiled GSDs and volume data from previous wildfire studies and conducted new fieldwork measuring GSDs and deposit volumes in PFDF deposits to fill this critical knowledge gap. Adding to the 25 GSDs and the 13 volume measurements from previous studies spanning the Intermountain West, we measured GSDs and volumes from an additional

30 PFDFs that occurred in 10 different wildfires across Utah. Altogether this represents the largest and most spatially extensive dataset of PFDF GSDs of which we are aware. Catchments that produced these PFDFs vary in upstream burn severity, area, slope, forest type, soils, climate, and geology. These metrics were all extracted as potential predictor variables for our statistical analysis. We will analyze these data using Random Forest and Multiple Linear Regression statistical modeling and investigate which landscape metrics exert the most control on PFDF GSD and volumes in the Intermountain West. We aim to generalize the results of our GSD model and to validate existing PFDF volume models for this region.

Denny Haynes, MS in Watershed Science

Major Advisor: Dr. Carl Saunders

Post-grazing season implementation monitoring protocols: an assessment of differences and potential for compatibility

Livestock grazing is the most widespread land management activity occurring in riparian areas on public lands in the western United States. Stream channel profile, streambank stability, streamside vegetation, stream sediment loads and stream temperature are all critical fisheries habitat characteristics that can be directly or indirectly affected by livestock grazing. These impacts have led to particular concern about grazing impacts on streams, especially those occupied by sensitive or endangered species. Therefore, public land managers and researchers have identified livestock grazing management as a priority for riparian area and stream conservation in the west. Federal agencies and monitoring groups use short-term indicators of livestock disturbance measured annually as proxies for longer-term effects on riparian areas and stream habitat conditions. Given limited resources and extensive federal mandates associated with riparian area monitoring, increased consistency and compatibility among monitoring protocols is needed to increase broad-scale applicability and effectiveness of monitoring results. Therefore, I am currently utilizing two research approaches for assessing the implications of methodological differences between two common post-grazing season implementation monitoring protocols, the PACFISH/INFISH Biological Opinion Monitoring Program's (PIBO) *Grazing Implementation Monitoring Methods for End of Season Use Indicators in Streams and Riparian Areas* (Saunders et al. 2019) and *Riparian area management: Multiple indicator monitoring (MIM) of stream channels and streamside vegetation* (Burton et al. 2011). My current research has four main objectives:

- (1) Determine whether the differences in the methods used between the two most commonly applied post-grazing season implementation monitoring protocols result in meaningfully different measurements of within-season livestock grazing.
 - (2) Identify which specific differences in methodology lead to meaningful data differences and how to best reconcile those differences to increase compatibility between the two protocols.
 - (3) Determine whether differences between the MIM and PIBO post-grazing season implementation monitoring protocols lead to differences between the protocols' abilities to detect the indirect impacts of within-season grazing on stream habitat conditions.
 - (4) Determine whether the protocols' abilities to detect the indirect impacts of within-season grazing on stream habitat conditions differ among designated monitoring area blocks and their associated environmental covariates.
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Alec Arditti, Ph.D. in Watershed Science

Major Advisor: Dr. Patrick Belmont

Wildfire-Induced Sediment Risk as a Function of Connectivity

Wildfire-induced flooding and sedimentation are among the greatest threats to watersheds, fish populations and reservoirs in the western US. Wildfire occurrence and severity has been on the rise due to climate change and historic forest management practices. Burned landscapes are highly susceptible to erosion and pose risks to watersheds long after wildfire occurs. Eroded sediment is routed from hillslopes into channels and then through the stream network during post-fire runoff events, which can then threaten downstream resources. Post-wildfire sediment transport is significantly influenced by watershed connectivity of the stream network. Sediment routing within the channel can be modified by the presence of bottlenecks. Sediment routing bottlenecks (SRB) occur in areas where sediment is trapped and/or deposited. SRB can also influence the volume of sediment that reaches downstream resources. These SRB are heavily controlled by the valley bottom setting, but can also be altered by large wood. Following wildfire, large wood recruitment to channels is seen to increase. Understanding how these controlling factors relate to SRB is imperative for predicting connectivity of a watershed. I will study the interaction between wildfire and SRB and how factors such as the valley bottom setting and large wood determine prevalence of SRB. I will do this by mapping locations where wood and sediment are deposited and persist over several years using a combination of aerial imagery, LiDAR and field verification. Next, I will link these

spatial datasets with watershed and wood characteristics through random forest modeling. I will then apply these findings to associate the effects of SRB to changes in geomorphology and sediment deposition impacts after wildfire.

Christy Leonard, Ph.D. in Watershed Science

Major Advisor: Dr. Jack Schmidt

Partitioning a flux-based and morphological sediment budget by sand-size class to understand where and why channel change occurs

Relatively little research has sought to define the linkage between sediment mass balance and resulting change in channel and floodplain form and habitat. A fundamental paradigm of geomorphology is that channel and floodplain form are largely determined by the stream-flow regime and the watershed sediment supply. When the supply of water and/or sediment change, accumulation or evacuation of sediment of the channel and/or floodplain typically occurs that may result in changes of the attributes and availability of aquatic or riparian habitat. Continuous measurements of sediment transport at segment-bracketing gaging stations allow for the construction of mass-balance sediment budgets that identify periods of sediment loss or accumulation; however, such measurements do not necessarily provide information about where the resulting channel change has occurred. In this study, we use a continuous mass-balance sediment budget and geomorphic analysis of channel change to evaluate the links among sediment flux, streamflow, and changes in channel morphology in part of the lower Yampa River, Colorado. Flux-based measurements of fine sediment transport show that the efflux of sand exceeded the influx in every year between 2013 and 2019, resulting in a deficit of $650,000 \pm 580,000$ metric tons of sand, which corresponds to between 0.02-0.30 meters of erosion averaged over the study area. The influx and efflux of silt and clay during the same period was approximately in balance. We segregated the flux-based sediment mass balance by sand-size classes and found that very fine sand accumulated during large floods that inundate greater than 50% of the recently formed floodplain surfaces, fine and medium sand evacuate regardless of flood magnitude, and there was no discernible change in coarse and very coarse sand storage. We defined several facies of in-channel alluvial deposits that have different grain size characteristics, and we explicitly linked changes in the volume of these facies to changes in different grain sizes of the partitioned flux-based sediment budget. We found that very fine sand accumulated in vegetated islands during large floods, which dampened the magnitude of total sand evacuation and led to the unexpected result that larger floods produced less erosion. The evacuation of fine and medium sand could not be linked to a net change in storage of any facies, and we propose that those sand-sizes are winnowed from the channel bed in response to the passage of a sediment wave initiated ~60 years ago. Results of this study suggest that the sign of the sediment mass balance maybe insufficient to predict the impending channel response, because channel change is driven by grain-size specific changes in sediment storage that maybe unrelated to the total sediment mass balance. We demonstrate that it is possible to explicitly link changes in a sediment mass balance to changes in channel form when the mass-balance is partitioned by grain size classes, assuming that the grain size characteristics of different facies can be defined.

Melissa Cobo-Arias, MS in Watershed Science

Major Advisor: Dr. Soren Brothers

Desiccation of Great Salt Lake (UT) is a significant source of anthropogenic greenhouse gas emissions

Anthropogenic desiccation has negatively impacted saline lake levels around the world. This exposes large areas of lake sediments to the atmosphere, producing elevated carbon dioxide (CO₂) emissions and contributing to atmospheric greenhouse gas (GHG) concentrations. We measured biweekly (spring to fall 2020) CO₂ dry fluxes from exposed lake bed areas of Great Salt Lake (Utah, USA), a large terminal lake experiencing declining water levels due to local consumptive water uses and diversions. We present the high inter-seasonal variability of these fluxes and discuss potential drivers of local variability. We also estimate the natural surface CO₂ fluxes of Great Salt Lake and present the net landscape outcome of local desiccation on statewide anthropogenic GHG emissions.

Macy Gustavus, MS in Watershed Science

Major Advisor: Dr. Janice Brahney

Microplastic attributes and outstanding sources to a model aquatic system in the Intermountain West

A surge in plastic use throughout the 20th and 21st century has resulted in an alarming increase in contemporary microplastic pollution. Plastic production has increased approximately 200 fold from the 1950s to 2018, skyrocketing from 2 million to 381 million tons produced per year. Plastic products break down to particles that are smaller than what the eye can see. These tiny pieces of our everyday lives are found in the deep sea, inside our homes, throughout freshwater resources, rooted in sediments, and in remote environments far from anthropogenic influence. Microplastic particles adversely affect the health of organisms ranging from aquatic species to humans. Research on microplastic fate and transport in freshwater systems, specifically on smaller particles that may pass through sampling nets, is lacking and in need of attention. The Logan River is a unique aquatic system where alpine environments meet urban and agricultural areas making ideal for microplastic source quantification and transport analysis. Grab samples will be collected using glass jars and taken from the thalweg in riffle sections of the river to target the smallest sizes of microplastics. Sampling will take place over a full-year period with focus on melt season and storm events to assess the possibility of hysteresis. Microplastics will be analyzed using three complementary techniques; visual counting, Fourier-transform infrared spectroscopy (FTIR), and thermal desorption coupled with gas chromatography and mass spectrometry (TD-GC/MS). Visual inspection will offer information on the number of particles present in a sample as well as particle size, shape, and color. FTIR will focus on microplastic polymer identification and mass quantification while TD-GC/MS will identify nanoplastic residue and contaminants associated with microplastic particles. This study will fill the knowledge gap related to smaller microplastic particles in freshwater environments and the global microplastic cycle.

Molly Blakowski, Ph.D. in Watershed Science

Major Advisor: Dr. Janice Brahney

Characterizing the composition and transport of dust from the Great Salt Lake playa

Human water use has drained the Great Salt Lake (GSL) to historically low levels, exposing a huge supply of fine-grained sediments to erosion and entrainment in the atmosphere. Dust plumes originating from the playa reduce local air quality and accelerate snowmelt in the Wasatch Mountains. The composition of dust from the GSL playa is of great concern because it contains heavy metals and other contaminants that have drained into the GSL over time. Yet, studies of dust generation from the GSL playa are just beginning. No studies to date have interrogated the sources of heavy metals to this growing dust source, and the degree to which heavy metals in GSL playa dust are available for plant uptake is unknown. Likewise, it has yet to be tested whether dust events along the Wasatch Front or rates of dust deposition to the Wasatch Mountains are correlated to GSL lake levels. Given these considerable knowledge gaps and the many environmental and public health consequences at hand, there is a great need for improved understanding of the composition and transport of dust from the GSL playa. My proposed research seeks to answer the following questions: 1) What are the sources of heavy metals to the GSL playa? 2) To what degree can heavy metals in GSL playa dust affect plants grown in farms and gardens downwind from the playa? 3) Can changes in regional air quality and dust deposition rates be explained by the decline of the GSL? 4) Is dust from the GSL playa transported to Cache Valley? I plan to address these questions and related sub-questions using mixed methods. My fieldwork plans include contemporary dust sampling at source and sink areas, as well as a lake sediment core. I will also conduct a greenhouse experiment. My methods involve geochemistry, a novel isotope tracing technique, regional meteorological records, remote sensing, air mass trajectory modeling, and meta-analysis. The results of my research will greatly expand the current understanding of risks associated with the decline of the GSL and can be used to inform future management and mitigation strategies.

Dale Fonken, MS in Watershed Science

Major Advisors: Drs. Mary Conner (WILD) & Timothy Walsworth

Identifying Optimal Stocking Strategies to Support Recovery of an Endemic Lake Sucker

Anthropogenic alterations to freshwater ecosystems have been associated with decreased biodiversity and extinction of native species. Endemic fish species such as the threatened June sucker (*Chasmistes liorus*) in Utah Lake, UT, are particularly vulnerable to extinction due to their limited native range. Recovery strategies for the June sucker have employed a suite of methods, but perhaps

the most prominent is artificial propagation to increase the abundance of spawning adults, as natural recruitment has been severely limited or absent for decades. Identifying the stocking strategies that most effectively increase adult abundance is a critical aspect of successful adaptive management. Over 800,000 June suckers have been stocked from various hatcheries, grow-out-ponds, and refuge populations since artificial propagation began in the mid 1990s. In addition to source variability, fish have been stocked at differing sizes and seasons, raising questions of efficacy among stocking methods. Here, I evaluated post-stocking survival to recruitment of June suckers using a Cormack-Jolly-Seber model with three covariates: stocking origin, stocking size, and stocking season. Survival was positively correlated with stocking size, with an apparent size-selective predation threshold occurring around 300mm. Additionally, survival of 300mm June suckers stocked in spring ($S=.45$, $CI[.39,.62]$) exhibited higher survival than summer ($S=.22$, $CI[.08,.60]$), and fall ($S=.21$, $CI[.07,.45]$). By identifying biotic and abiotic variables which affect survival, I highlight operational changes which maximize productivity of hatchery programs, a critical component of native fish recovery programs throughout the intermountain west.

Martinique Chavez, MS in Ecology

Major Advisor: Dr. Phaedra Budy

Big moves by a little fish: Characterizing movement patterns of the endangered Rio Grande Silvery Minnow in a fragmented river

Most large rivers in North America are fragmented by dams that modify natural flow regimes, compromise connectivity of freshwater ecosystems, and imperil freshwater fishes dependent upon unrestricted movement for long-term persistence. Coincident with widespread river fragmentation, are the declines of numerous endemic desert fishes. The Rio Grande Silvery Minnow (*Hybognathus amarus*, RGSM), has experienced a dramatic 95% reduction in its historical range. The overall goal of this study is to document and better understand the movement ecology and patterns of RGSM, and specifically address whether they currently have the ability to move long distances in either direction. We used Passive Integrated Transponder (PIT) tags in stocked RGSM with stationary and mobile PIT-tag antenna systems to detect and track movement patterns across time and space. To date, we have released five batches of PIT-tagged RGSM, totaling nearly 24,000 fish. Of those, 10,380 have been detected at least once, an extremely high resight rate (43%). A total of 8,615 individuals made at least one movement (e.g., detected at two different locations). The mean distance moved by PIT-tagged RGSM was 10.6 km, and the maximum distance moved was 142.9 km. Surprisingly, a total of 79 individuals passed upstream through the San Acacia Dam. The large proportion of fish which remain just downstream of the dam long after release may indicate they are attempting to move and disperse upstream. Our data to date suggest RGSM are highly mobile, with the ability to make targeted long distance movements both upstream (to the extent possible) and downstream. As indicated by repeated detections over time, this study design has been very successful, despite the small size of tagged fish and their hatchery origin. Direct evidence of RGSM movement patterns may provide crucial insights that could help target recovery efforts and ultimately aid in meeting management goals.

Tansy Remiszewski, MS in Ecology

Major Advisor: Dr. Phaedra Budy

The response of imperiled fishes to the extreme geomorphic change in a historically degraded desert river

Global freshwater biodiversity is threatened by a wide array of hydrologic alterations resulting from land-use alteration, water development and climate change. Coinciding with these alterations is increased habitat simplification in rivers occupied by many endangered fishes, resulting in population declines and widespread extirpation. Populations of three protected, endemic, desert river fishes (bluehead sucker *Catostomus discobolus*, flannelmouth sucker *C. latipinnis*, and roundtail chub *Gila robusta*) collectively known as the "Three Species", have experienced more than a 50% reduction in distribution over the past few decades. The overall goal of this study is to document extreme geomorphic change in a historically degraded desert river tributary as it relates to the creation of fish habitat and use by fish species. In 2010, a large reach of the San Rafael River (SRR; tributary of the Colorado River Basin (CRB)), began to actively change from a simple single-thread channel to a complex shallow, multi-thread channel. We used ArcGIS and field surveys to document changes in this river system from the establishment of the habitat feature. We also monitored movement and habitat use of the lower San Rafael River by protected, endemic river fishes including bonytail (*Gila elegans*). Based on preliminary analyses, this altered reach of river is more diverse than any other region along the lower SRR with affected reaches containing 17% more complex habitat on average than reference reaches. We observed that of 3,546 released and Passive Integrated Transponder (PIT) tagged bonytail, 79% remained in the system for up to 3 months. Additionally, based on electivity analyses, 5 of the 8 sampled species were selecting this relatively new complex habitat. Direct evidence of significant geomorphic

change, as well as the retention of endemic fishes in the habitat feature, could offer insight into “low tech” restoration opportunities and recovery of endangered desert fish species.

Katy Gardner, Ph.D. in Watershed Science

Major Advisor: Dr. Charles Hawkins

Does salinity affect the distribution of stream macroinvertebrates?

Increasing salinization of freshwaters threatens freshwater biodiversity. Freshwater ecosystems vary naturally in both ion concentration and composition, and field observations imply that macroinvertebrate taxa vary in the range of salinity levels they can tolerate. As salinity levels rise, it becomes increasingly more important to understand these tolerances and how they influence macroinvertebrate distribution. Field data are often used to infer tolerances of different species to salinity and other stressors. However, such correlative observations may not always accurately describe stressor-specific tolerances because many environmental variables naturally covary with one another. These confounding relationships, such as between salinity and temperature or between specific ions, potentially compromise our ability to identify the actual mechanisms influencing species distributions. Temperature has been shown to exacerbate the effects of salinity, complicating the relationship of these covarying stressors further. The specific dissolved inorganic ions contributing to total salinity differ across waterbodies, and measures of total salinity (such as conductivity) will not identify differences in the relative importance of specific ions on species abundance and distributions. These constraints make inferring tolerance from field data alone difficult. Despite this difficulty, there are efforts to generate salinity criteria from field observations to be used in stream management. Such studies should be rigorously tested and be robust to differences in sample size. The results of field-derived analyses may be influenced by subsample size and thus potentially misrepresent a species true tolerance. For these reasons, it is critical to experimentally verify field-derived estimates of species' environmental tolerances. Long-term, chronic-exposure experiments should be most useful in validating such relationships because they best mimic exposures in nature, but very few such studies have been conducted on freshwater macroinvertebrates. My dissertation research focuses on four research questions that collectively will provide a stronger understanding of the effect that variation in salinity has in influencing the abundance and distribution of stream macroinvertebrates. I will first use field data to develop species distribution models to infer species' tolerances to salinity and specific ions (Objective 1). Next, I will determine if individual size of several species vary across known salinity gradients to test whether growth is affected by salinity levels (Objective 2). Third, I will conduct chronic-exposure rearing experiments in the lab to verify these field-derived tolerances (Objective 3). I will use survivorship and growth metrics to assess if field-based correlations are consistent with causal effects of salinity. In the experiments, several different taxa will be exposed to six concentrations of NaCl and a CaSO₄/MgSO₄ mixture ranging from 0-1,500 mg/L. To determine if the effects of salinity on growth and survivorship depend on temperature, I will include six temperature treatments spanning a temperature gradient of 10°C across each salinity treatment. Last, I will assess the adequacy of methods used by the USEPA to establish salinity criteria from field observations and determine whether these methods are robust to variation in sample size, to better inform future assessment efforts (Objective 4).

Manny May, MS in Fisheries Biology

Major Advisor: Dr. Timothy Walsworth

Assessing aquatic macrophyte recovery and the associated fish community response to common carp removal efforts in Utah Lake

Restoring beneficial ecosystem services and biodiversity in large, degraded freshwater systems can prove difficult, requiring large-scale manipulations and decades to demonstrate a detectable response. Utah Lake (Utah) is a large, shallow, lake once characterized by clear water and a diversity of native macrophytes. However, following multiple anthropogenic alterations in the watershed over the past century, including the establishment of non-native species, excessive nutrient loading, and rapid water level fluctuations due to irrigation and multi-year drought, the lake is now characterized by eutrophic conditions limited in native macrophyte diversity. These changes have resulted in the extirpation, extinction, or endangerment of multiple endemic native fish species. Current restoration goals focus on recovering submerged macrophytes, which are assumed to be essential for the recruitment of desirable fish species, through large-scale removal of common carp. However, despite over a decade of extensive carp control efforts that have successfully reduced carp biomass by over 75%, Utah Lake remains largely phytoplankton-dominated with limited recovery of submerged macrophytes. Here, I present the proposed approach for a new study to identify environmental factors limiting the abundance and distribution of submerged macrophytes, and examine how the fish community is structured relative to

macrophyte habitat availability in Utah Lake. Additionally, I will address future uncertainties of how multi-year-drought conditions and water management may affect the recovery of submerged macrophytes and desirable fish species. Ultimately, my project results can inform managers of the conditions necessary for restoration benefits to be realized and shift Utah Lake back toward a diverse macrophyte-dominated ecosystem, thus supporting native and desirable species recovery, increasing biodiversity, and bolstering ecosystem services.

Coryna Hebert, MS in Ecology

Major Advisor: Dr. Karin Kettenring

Microtopography of Great Salt Lake Wetlands

Microtopography (small change in soil surface elevation that creates vertical relief <1m) is known to have a critical functional role in many wetland ecosystems. There is evidence that microtopography facilitates species richness, can buffer against inconsistent hydrologic regimes, and provides fundamental structural components to wetlands. In the vast wetlands of the Great Salt Lake, Utah, microtopography has not been characterized or evaluated for its role in driving these factors. Great Salt Lake wetlands have lost abundant critical wildlife habitat from the rapid expansion of the invasive grass, *Phragmites australis*. Refined techniques, particularly seed-based restoration, are required to improve establishment of native plant communities following *Phragmites* control. There are also underlying questions about the role of *Phragmites*, a known ecosystem engineer, and its potential alteration of microtopography in this landscape. This research aims to a) characterize the relationship between microtopography and plant communities in Great Salt Lake wetlands and b) explore the use of artificially induced microtopography to improve seed-based revegetation outcomes. In the summer of 2020, twelve plant communities and their corresponding microtopography were surveyed to characterize what types of microtopography are present in this system. Average relief values fell between 2.5 and 10 cm across all plant community types. Additionally, a pilot experiment was conducted to test the effect of four distinct microtopography treatments on native plant community composition facilitated by two native seed mixes. Microtopography treatments had no significant effect on plant community composition but more evidence is needed to determine its role and potential importance in this system. The observation study and field experiment are critical first steps in understanding microtopography in this unique wetland complex which in the future can better facilitate restoration goals.

Rachel Watts, MS in Watershed Science

Major Advisor: Dr. Janice Brahney

Effect of high flow events on P mobility

Phosphorus is a key limiting nutrient in watershed systems, influencing production, species composition, and habitat conditions. Currently, important questions still remain on the form, transport, and bioavailability of phosphorus' compounds during high flow events. Specifically, it is uncertain how hydraulic shear stress, period between storms, and riverbed composition interact to influence the mobilization of P and, consequently, the trophic status downstream. It is also unclear how river sediment composition influences the bioavailability of P during high flow events. Our hypotheses are: 1- Hydraulic shear stress influences mobility of particulate and dissolved P, and 2- Fine sediment composition influences P bioavailability. Here, we plan to test these hypotheses through in situ river manipulation in New Mexico's Jemez watershed. Riverbed and suspended sediments mobilized during high flow events will be analyzed for TP, SRP, and PP to evaluate the potential implications to the ecosystem. Results will be used to detect P hysteresis patterns which will illustrate whether the sources of these P fractions are proximal or distal. To determine the potential of phosphate desorption from streambed sediments once they are suspended in the water column, and relate this to streambed sediment composition, sorption experiments on streambed sediments from each reach will be used to determine EPC. It is anticipated the results of this experiment will show that high flow events have a direct effect on P bioavailability in that: 1-Increased shear stress in the water column will lead to river armor movement, mobilizing more phosphorus into the water way via disturbance of finer sediments, 2- Increased concentrations of P will alter the EPC, impacting downstream water quality.

Gordon Gianniny, MS in Watershed Science

Major Advisor: Dr. Janice Brahney

Are warming soils leading to phosphorus enrichment in remote mountain lakes

A substantial portion of the world's population relies on mountain watersheds for a source of clean drinking water. However, recently observed increases in dissolved phosphorus (P) concentrations in these systems could have serious implications for both local ecosystem function and downstream water quality. Mountain lakes are often P limited, so even relatively small increases in P concentrations may have outsized impacts on ecosystem structure and function. In extreme cases, rising P concentrations may cause harmful eutrophication events that have historically been very rare in mountain watersheds. Previous research has established that recovery from acidification and increasing dust deposition may explain the observed P increases in some catchments, but these mechanisms do not explain observed P increases in systems that do not have a history of substantial acid or dust deposition. In light of this discrepancy, we propose to test a fourth potential mechanism: rising soil temperatures. Higher soil temperatures have been shown to increase dissolved organic carbon (DOC) production and speed up soil organic matter decomposition, so it is reasonable to expect that P production may follow a similar pattern. Therefore, we hypothesize that exposure to higher temperatures will lead to increased labile P production in mountain soils. Specifically, we will test how P production in high-elevation soils responds to warmer, drier climatic conditions by performing reciprocal soil core transplants along temperature/elevation gradients in the Sierra Nevada Mountains, CA, and San Juan Mountains, CO. We will also test how soils from a wider variety of mountain ranges and elevations respond to higher temperatures using soil samples collected at 1,000 ft. intervals in five different mountain ranges around the western U.S. We will incubate these samples at three different temperatures in growing chambers at USU to test temperature effects in a more controlled setting. By evaluating the role of rising soil temperatures in P production in mountain soils, this study has the potential to fill a critical gap in our understanding of the mechanisms driving P enrichment in remote mountain catchments.

Abstracts: Departmental Seminar

Umarfarooq Abdulwahab, Ph.D. in Ecology

Major Advisor: Dr. Charles Hawkins

Developing a data-driven decision support system to improve the conservation of imperiled species on Department of Defense and surrounding lands in California

Development of effective conservation strategies for imperiled species is constrained by the quality of data describing the known locations of species and the methods available to assess tradeoffs between protection and other land use needs. Department of Defense (DoD) lands occur throughout the United States, and all would benefit from more effective conservation plans. The primary aim of my research is to develop a data-driven decision support system to help managers identify the mixes of land use that optimally protect several amphibian and reptile species of concern while minimizing the costs to other activities on DoD lands in California. Target species include California Red-legged Frog, Foothill Yellow-legged Frog, Arroyo Toad, Western Spadefoot, and Western Pond Turtle. My research questions include 1) what effect does choice of climate data have on the performance and interpretation of species distribution models (SDMs), 2) how well can we predict spatial variation in the risk of an important amphibian pathogen – the chytrid fungus (*Batrachochytrium dendrobatidis*), 3) how comparable are machine learning and occupancy models in predicting the distributions of the sensitive and rare target species, and 4) can the use of the Marxan optimization tool aid in conservation planning. Objective 1 is the focus of this presentation. The proliferation of readily-accessible climate data is stimulating the increasing use of species distribution models (SDMs) in conservation planning and management. However, it is uncertain how sensitive models are to the choice of climate data used. I compared the performance of maximum-entropy SDMs developed for six imperiled California species (4 amphibians, 2 reptiles) based on seven different climate datasets (WorldClim, Chelsa, TerraClimate, Climate Research Unit Time-Series [CRU-TS], PRISM, StreamCat, and EarthEnv). For each species, I used a standardized, objective procedure to select climate predictors from each dataset; assessed performance with standard metrics; and compared variable importance scores, partial dependence plots, and predicted distributions. SDM performance was sensitive to the climate dataset used. For some species, the use of similar climate predictors from different datasets produced opposite responses. Resolutions of the climate data did not strongly affect SDM performance. For two species, the spatially coarsest data (CRU-TS) performed less well than models based on the other data sources. For some species, freshwater-focused datasets produced better models than terrestrial-focused datasets. Some models overpredicted and others underpredicted distributions

compared with historical range maps. Care should be taken when developing, applying, and interpreting climate-based SDMs, and ensembles of models may be needed to estimate uncertainties in predictions.

Ali Farshid, Ph.D. in Watershed Science

Major Advisor: Dr. Sarah Null

Utilizing green infrastructure (GI) to mitigate the adversarial effects of changes to open spaces

There is a land-use crisis in the USA. We are consuming our open spaces with subdivisions, strip malls, parking lots, and similar developments. According to a USDA Forest Service study (2006): America loses 4,000+ acres per day of open space or 3 acres per minute. We are creating urban sprawl and fragmenting natural systems. The modifications on the open spaces change the hydrological cycle, create engineered hydrological flow paths, reduce capacity for water storage, increase rapid post-event runoff, and generate flashy hydrological systems. These modifications will exacerbate flooding and erosion in natural systems, worsen pollutant delivery to downstream water bodies, and impair aquatic habitats. In addition, disinvested communities can suffer more from these adversarial effects because they normally receive less attention and budgets to alleviate the negative impacts. One way to mitigate these adversarial effects is to implement green infrastructure (GI) throughout urban watersheds. In my Ph.D. research, I will be trying to address the following research questions:

- 1) What are the most effective types of GI practices and their essential design parameters to efficiently remove Total Suspended Solids (TSS) and prevent Dissolved Oxygen (DO) depletion from urban runoff based on published data? (Chapter 1)
 - 2) What is the best selection of location, type, and design parameters for high-ranked GI practices (the outcome of chapter 1) to be implemented in a mixed-used watershed in order to effectively remove TSS from urban storm water runoff and minimize the implementation costs? (Chapters 2 & 3)
 - 3) How can we quantify inequity in disinvested communities when it comes to urban storm water management? (Chapter 4)
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Luke Gommermann, Ph.D. in Watershed Science

Major Advisor: Dr. Jack Schmidt

What Does it Take to Maintain an Active Channel? Assessment, Application, and Methodological Expansion of the Northern Colorado Plateau Network's Big Rivers Monitoring Protocol in Canyonlands National Park and Dinosaur National Monument

Situated within a warming and over-allocated water landscape, National Park Service (NPS) natural resource managers of the Upper Colorado River Basin face a growing need to justify instream flows that maintain riparian and riverine ecosystems within park units. To support this effort, the NPS Inventory and Monitoring Division's Northern Colorado Plateau Network (NCPN's) initiated its Big Rivers (BR) monitoring protocol in 2010. The NCPN BR protocol combines intensive, small-scale field sampling with broad-scale remote sensing analysis to track changes in channel form and riparian vegetation along the Colorado and Green Rivers within Canyonlands National Park (NP) and the Green and Yampa Rivers in Dinosaur National Monument (NM). In this proposal, I first aim to compare findings from field monitoring and remote sensing methods. Based on these results, I will develop an "environmental currency" that specifies how varying characteristics of each river's interannual and intraannual water flows advantage or disadvantage desired and undesired vegetative and geomorphic resources of these two NPS park units. Secondly, to assess woody riparian vegetation seedling phenology and survival across the Upper Colorado River Basin, I propose to develop a citizen science project and expand NCPN BR field methodology. Collectively, these objectives will provide NPS scientists and managers with detailed ecological and geomorphic justification for requesting future instream flows and describe characteristics of water flows that reduce successful recruitment of vegetation species that are implicated in driving or promoting the loss of active channels along rivers of the Upper Colorado River Basin.

Jack McLaren, Ph.D. in Ecology

Major Advisors: Drs. Soren Brothers & Phaedra Budy

Reading the water: towards a better understanding of trout habitat availability, selection, and productivity in the Henry's Fork of the Snake River, Idaho

The effect of macrophytes on trout habitat and productivity is not well studied given the prevalence of macrophytes in trout-supporting river systems and the economic importance of riverine trout fisheries. The Henry's Fork of the Snake River ("Henry's Fork") in Idaho is one such river with large beds of submerged macrophytes alongside a world-famous, economically-important trout fishery. We used traditional snorkel surveys, water quality monitoring, physical habitat surveys, bioenergetic analyses, and aerial photography across a spatiotemporal gradient of macrophyte coverage to investigate how trout habitat availability, quality, and selection relates to macrophyte coverage. We hypothesized submerged macrophytes create suitable microhabitats for adult trout in river ecosystems by providing overhead cover from predators and increasing bioenergetic potential. Surprisingly, based on snorkeling surveys across all locations, we found that adult trout tend to avoid microhabitats with macrophytes. However, based on drone photography and physical monitoring, we discovered macrophyte coverage influences geomorphology to create a riverscape of complimentary physical habitats, including habitats preferred by adult trout. Subadult and juvenile trout showed more of a tolerance for macrophyte growth. All trout in macrophyte-poor and macrophyte-rich reaches appeared to have less of an aversion to macrophytes. I hypothesize that differences in habitat selection across fish size and location can be explained by bioenergetics and thereby reach-scale productivity. Therefore, future work will focus on reach-scale trout productivity, focusing on the mechanisms connecting macrophytes, bioenergetics, nutrient dynamics, and ecosystem productivity. Our study helps reduce uncertainty about trout habitat and productivity in macrophyte-dominated rivers and could reveal potential management and monitoring actions to improve trout productivity in these systems.

Emily Tarsa, Ph.D. in Ecology

Major Advisor: Dr. Karin Kettenring

The role of native plants in facilitating healthy wetlands

Native plants play a large role in facilitating healthy wetlands. In Great Salt Lake wetlands, which support millions of migratory birds and provide important ecosystem services, native plants have been lost to invasive species and other disturbances. Returning native species to these wetlands is critical to improve habitat quality and ecosystem function. Sowing native seeds is a promising revegetation strategy, but outcomes are often unpredictable and seedling mortality can be high. In this presentation, we will explore how functional regeneration traits can be used to improve our ability to make targeted restoration decisions, such as which species should be sown, where seeds should be sourced, and what environmental conditions optimize seedling survival. This targeted approach provides valuable information on effective seed-based restoration methods to conserve, restore, and manage wetlands into the future.

Marshall Wolf, Ph.D. in Ecology

Major Advisor: Dr. Edward Hammill

Ecosystem Response of an Impaired Watershed to Beaver Dam Analog Restoration

Within Western North America, beaver (*Castor canadensis*) are a keystone species whose ecosystem engineering alters the structure and functioning of ecosystems thereby providing habitat for a multitude of taxa and critical ecosystem services to society. Historical fur trapping, agriculture and anthropogenic land use change have reduced the influence beaver have on ecosystems and the suitability of certain streams for beaver colonization. In areas where habitat or food are limiting for beaver, mimicry of their hydro-engineering through the building of beaver dam analogs (BDAs) is fast becoming the preferred strategy to restore lost ecosystem function and services. Most of our knowledge of our knowledge on BDAs impact to stream ecosystems comes from incised streams within relatively rural watersheds. Little is known on how BDAs may influence streams with water quality impairments in more developed watersheds. My work is quantifying the ecosystem level responses to BDA restoration within the 303(d) water quality impaired East Canyon Creek near the rapidly urbanizing Park City, UT. I am accomplishing this goal through a multi-faceted study of BDA and control sites using a Before-After-Control-Impact study design. I am addressing three main questions: (1) How do BDAs influence riparian productivity within a wide floodplain (> 50 m) geomorphic setting? (2) What are the

geomorphic responses to BDAs within a wide alluvial valley? (3) How does a diverse fish community respond to BDA restoration in a water quality impaired stream? Answering these questions is critical to demonstrating the efficacy of utilizing BDAs in impaired or urbanizing watersheds and enhancing our understanding of the impacts of beaver mimicking restoration across a variety of geomorphic settings.

