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Citizen science as a long-term environmental baseline: assessing impacts of a small dam removal in Montana, USA

Bethany Blakey[1], Natalie Bursztyn[2]

[1]Department of Watershed Science, Utah State University, Logan, 84321, USA
[2]Department of Geology & Environmental Science, James Madison University, Harrisonburg, 22807, USA

Correspondence to: Natalie Bursztyn (c9wsgy@jmu.edu)

Abstract. As dam removals increase in frequency across the U.S., most research has focused on the impact of larger dam removals, despite the removal of small dams being much more common. There are hundreds of small dams in Montana, and this research investigates impact on stream ecology and morphology using citizen science data collected over eight years spanning before and after a 2020 small dam removal in Rattlesnake Creek. We analyzed pebble count grain size distributions and aquatic macroinvertebrate biotic indices from 2017 to 2024 to assess changes in sediment transport and macroinvertebrate population as well as evaluate the efficacy of citizen science for long-term stream monitoring. Our analysis includes comparisons of pre– and post–dam removal data collected from above and below the dam site. Our findings revealed no significant changes in grain size or macroinvertebrate index values between upstream and downstream reaches post–dam removal, suggesting that the removal of this small dam had minimal detectable impact on sediment transport and macroinvertebrate communities within the study period. Our study also demonstrates the capacity for citizen science programs to effectively collect robust and valuable datasets. This study underscores the importance of meticulous data management along with the potential for, and challenges of, citizen science for environmental research. We provide recommendations for "best practices" to improve future citizen science monitoring and informing decision-making for future dam removals, particularly for the nine dams further upstream within the Rattlesnake Creek watershed.

1 Introduction

The U.S. has an estimated 2.5 million dams, the majority of which are under 1.83 m tall and are classified as small dams (Brewitt & Colwyn, 2019; Kibler et al., 2011). A dam serves as a barrier to more than just water, blocking the transport of sediment, logs, nutrients, and passage of fish. As a result, dams can negatively impact the health of the stream, decreasing the presence of certain biota and hindering the growth of juvenile fish (Hart et al., 2002; Lu et al., 2022). However, particularly for the removal of historic dams, the rapid release of sediment and woody debris can negatively impact both species as well (Hart et al., 2002). Understanding how small dam removals affect the geomorphology and ecology of a stream is essential to understanding the extent of impacts on a stream from dam removal. Given the diverse geographical distribution of dams in the

https://doi.org/10.5194/egusphere-2025-6128
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United States and the role of sediment size, channel slope, flow, and other watershed-specific variables on creek restoration, it is important to understand the effects of small dam removal in specific environments (Hart et al., 2002; Kibler et al., 2011). In addition, most studies lack the duration necessary to determine long-term impacts of dam removal (Hart et al., 2002). By understanding how small dam removals in Montana have impacted waterways, the effects of dam removal can be more accurately anticipated when proposing similar projects in the Pacific Northwest. Advancing the science on small dam removals will help quantify the impact of these removals and promote healthier streams for ecological, societal, environmental, and recreational benefits. Especially relevant to this study site in Rattlesnake Creek, Montana, are the seven additional dams upstream in the Rattlesnake Wilderness (Rice & Armatas, 2024; Rattlesnake Wilderness Dams, 2024). The present study will help determine how their removal may impact the creek.

The Watershed Education Network (WEN) is a non-profit organization in Missoula, Montana, that has been leading citizen science efforts locally for 21 years. Stream Team is a WEN citizen science program that engages community members of all ages and backgrounds to monitor two creeks in Missoula, collecting valuable scientific data to document long-term trends in discharge, water chemistry, vegetation, aquatic macroinvertebrates, pebble counts, and cross-section profiles. Participating in citizen science endeavors has shown to improve individuals' knowledge of the scientific process, and community-based scientific monitoring gives voices to people who otherwise would not be in environmental conversations (Bonney et al., 2015). Citizen science is an especially effective method of environmental education when combined with focusing on local environmental issues, taking action, and reporting data (Ardoin et al., 2019). Furthermore, citizen science allows data collection on a spatial and temporal scale that would otherwise be difficult to obtain without significant funding, and by establishing "best practices" citizen science can meet the standards of data collection and further scientific research (Rubio-Iglesias et al., 2020)

This research seeks to answer the following questions: (1) How has Rattlesnake Creek changed since the dam removal in 2020? (2) Can citizen science projects effectively monitor local streams?

2 Background

2.1 Small dam removal in the western United States

Research on the removal of small historic dams has shown the ecological benefits of small dam removal (Abbot et al., 2022; Orr et al., 2008; Tullos et al., 2014). For most dam removals, no data is collected, and most studies focus on short-term post–dam removal impacts and include little to no pre–dam removal data (Bellmore et al., 2016; Foley et al., 2017). Some positive impacts of dam removal have been identified as the return of macroinvertebrate communities, dissolved oxygen, and sediment composition to healthier or above-dam levels (Abbot et al., 2022; Mahan et al., 2021; Orr et al., 2008; Tullos et al., 2014). While the impacts of small dam removal are mostly positive, studies show that the release of trapped sediment post–dam

https://doi.org/10.5194/egusphere-2025-6128
Preprint. Discussion started: 2 January 2026

removal can initially lower water quality (Orr et al., 2008), decrease macroinvertebrate diversity, and allow the downstream spread of invasive species (Mahan et al., 2021). The resilience of a river to dam removal depends on several factors, including response to this pulse in sediment, the magnitude of the changing conditions, the complexity and connectivity of the creek, and whether there is enough energy in the creek to process the disturbance and return to its natural state (Tullos et al., 2014).

Most research conducted on small historic dam removals has been focused on the eastern United States (Tonitto et al., 2016). Similar results may be expected in the western US in terms of hydrologic flows, sediment transport, and channel evolution; however, each of these variables are impacted by the specific watershed environment and require local studies. Given the complexity of how streams respond to the changes resulting from dam removal, it is important to build upon the existing research with additional studies, especially those contributing to the emerging dataset of the western US.

2.2 Geographic setting of Rattlesnake Creek, Montana

Rattlesnake Creek is a perennial, third-order tributary to the Clark Fork River northeast of the city of Missoula, Montana, in the Pacific Northwest (Fig. 1). The upstream portion of the creek flows through the Rattlesnake Wilderness area managed by the U.S. Forest Service. The watershed outlet is at the confluence with the Clark Fork River (Fig. 1a; 46.86737°, -113.98562°). Its total drainage area is 210 km^2 and flows for approximately 37 km. Rattlesnake Creek runs through the valley between Stuart Peak (2432 m elevation) and Mineral Peak (2270 m elevation). The total relief of the watershed is 1655 m with a mean basin elevation of 9177 m. Mean annual precipitation of the watershed is 102.2 cm, mean annual temperature is 3.95° C, and about 81% of the watershed is forested (USGS, 2019).

https://doi.org/10.5194/egusphere-2025-6128
Preprint. Discussion started: 2 January 2026

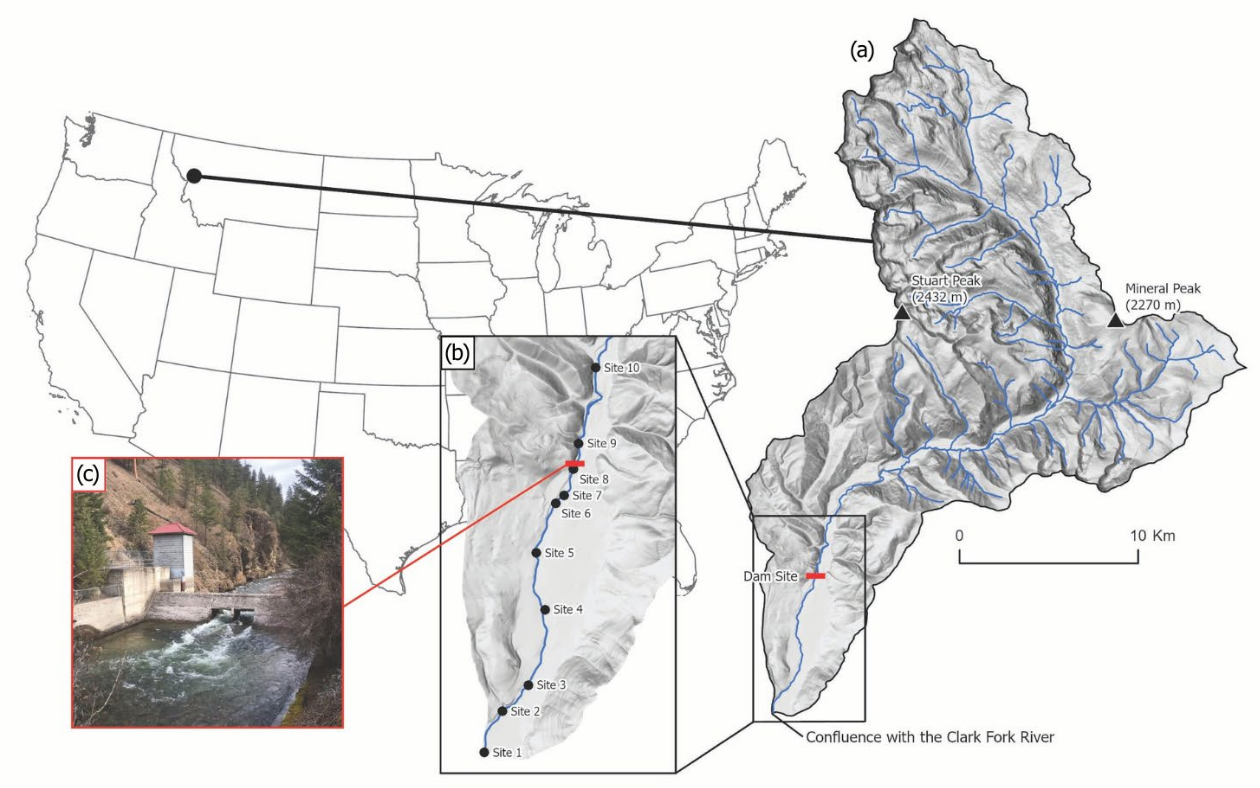

Figure 1: Location of the Rattlesnake Creek watershed (a) in Montana, United States. The Stream Team monitoring site locations are indicated along with the dam site (marked in red). Downstream sites 1–8 are the impact sites (b), upstream sites 9 and 10 are the reference sites (b), and a photo of the dam (c) before removal and after permanent opening of the sluice gates is shown (from TU).

An active stream gage managed by the Montana Department of Natural Resources and Conservation (MDNRC) is located at the upper end of Greenough Park, 2.3 km from the outlet of Rattlesnake Creek into the Clark Fork River. The upper 98.8% of the watershed is discharged through this gaging station. This station began recording in 2017, documenting discharge that ranges from 0.23 m^3/s to 31.8 m^3/s, with an average annual discharge of approximately 3.0 m^3/s. There is also an abandoned USGS gage (12341000) on the creek that operated from 1899 to 1967 and is located 270 meters upstream from the outlet to the Clark Fork River. In its headwaters, Rattlesnake Creek is fed by approximately 45 high-elevation lakes, eight of which are dammed (Rice & Armatas, 2024). The dams were built between 1911 and 1923 to increase water storage for the City of Missoula. In 2024, the McKinley Lake dam was removed, leaving seven dams in the wilderness.

2.3 Citizen science and public engagement in the environment

Getting the public involved in environmental education promotes actions, behaviors, and improvements for the environment (Ardoin et al., 2019; Church et al., 2019; Frigerio et al., 2021). The most effective environmental education programs focus on localized environmental issues, collaboration with scientists and resource managers, and taking actions that lead to physical environmental improvements (Ardoin et al., 2019). Citizen science is an especially effective method of environmental education, as it involves local focus, taking action, and reporting and has shown improvement in the scientific knowledge of participants (Ardoin et al., 2019; Bonney et al., 2015; Frigerio et al., 2021). Community-based scientific monitoring also helps shape scientific questions to address community needs and gives community members opportunities to engage with local environmental issues and take environmental action (Ardoin et al., 2019; Bonney et al., 2015; Novacek, 2008).

Citizen science is also an effective means for collecting data at temporal and spatial scales that are often not possible otherwise (Blake & Rhanor, 2020; Church et al., 2019; Deacon et al., 2023; Rubio-Iglesias et al., 2020). Data collected by citizen scientists raises concerns for data quality and maintaining public trust in scientific data, but the potential for citizen science to advance environmental research is much greater than the concerns (Rubio-Iglesias et al., 2020). While some researchers have found that citizen science does not produces accurate enough data for scientific research (Aceves-Bueno et al., 2017), direct comparisons between data from professional scientists and citizen scientists are not appropriate for assessing quality due to different methods and the ability to find and correct for patterns in citizen science data (Specht & Lewandowski, 2018). Importantly, citizen science commonly produces data that is scientifically sound and of high enough quality to use in scientific research, especially when data quality is documented (Ardoin et al, 2019; Deacon et al., 2023; Downs et al., 2021; Kosmala et al., 2016).

2.4 The Watershed Education Network and the Rattlesnake Creek project

WEN's mission is to 'foster knowledge, awareness, and appreciation of watershed health through citizen science, youth and school engagement, and outreach to our [sic] communities' (WEN, 2025). WEN organizes school programs for rural and under-served schools in Western Montana, a Backyard Citizen Science program to give families kits to monitor water near their homes, Backcountry Stream Corps to monitor large woody debris, groundwater monitoring excursions, and Stream Team to monitor Rattlesnake Creek and Grant Creek (Novak, October 21, 2025). Stream Team's monitoring of Rattlesnake Creek began in 2017, 3 years before the dam removal in 2020, and has been ongoing post–dam removal with annual monitoring of locations above and below the dam site (Fig. 1b). Throughout this project, WEN has involved hundreds of citizen scientists who have collectively volunteered over 4,000 hours from 2017 to 2024 (Fassnacht, March 30, 2025).

The downstream-most dam on Rattlesnake Creek was located 8 km from the confluence with the Clark Fork River (Fig. 1). The dam was constructed in 1901 and was 18 m wide, 3 m tall, and 4.5 m thick, and at that location, blocked 95% of the watershed. The reservoir provided drinking water for the City of Missoula until 1983, when, due to giardia concerns, the City shifted to using groundwater (TU et al., 2021). The reservoir was maintained as a backup water supply, but because Rattlesnake Creek supports native species of fish, including bull trout (*Salvelinus confluentus*), westslope cutthroat trout (*Oncorhynchus*

https://doi.org/10.5194/egusphere-2025-6128
Preprint. Discussion started: 2 January 2026

clarkii lewisi), longnose dace (*Rhinichthys cataractae*), and mountain whitefish (*Prosopium williamsoni*), a fish ladder was installed in 2003. The fish ladder had an estimated 50–90% efficiency (Fassnacht, March 30, 2025; Knotek et al., 2020; Novak, October 21, 2024). By 2011, the reservoir was no longer being used as a backup water supply, and in 2012 the dam sluice gates were permanently opened, allowing passage of water, fish, and sediment during moderate to low flow levels through the holes that were previously the sluice gates (Fig. 1c). During high flow, however, the water velocity through the sluice gate opening was too high for spring fish migration (TU et al., 2021).

In 2017, the City of Missoula obtained ownership of the dam and agreed to work with Trout Unlimited (TU) to develop a plan for its removal due to safety and conservation concerns related to the dam's deterioration. In 2020, the dam removal project began: Rattlesnake Creek was dewatered in July, and the stream channel and banks were reconstructed using gravel, logs, brush, cobbles, and boulders from the site. In total, over 300 meters of stream were reconstructed by the completion of the project in October 2020 (TU et al., 2021). The total cost of the dam removal was 1.1 million USD, and Rattlesnake Creek remains heavily dammed upstream in the wilderness area (Rice & Armatas, 2024).

During the planning stages of the dam removal, TU gave funds to WEN to support monitoring the health of the creek before and after the dam removal. This study analyzes the data collected by citizen scientists from WEN's Stream Team program, which received supplemental support from the Open Rivers Fund and other partners to monitor Rattlesnake Creek's response to the removal of this small dam. The Stream Team data will be used to quantify impact from the removal of the dam, assess the efficacy of the citizen science stream health monitoring protocol, and contribute to the broader understanding of how similar small dam removals impact streams in the Pacific Northwest.

3 Methods

3.1 Stream Team: citizen science data collection

WEN's Stream Team is a citizen science program where community members volunteer to monitor various stream attributes. Volunteers, including families, students, retirees, and community members, meet every Sunday from August to November. The program has been going on for Rattlesnake Creek from 2017–2024. Stream Team collects a variety of stream health monitoring data that includes cross-sectional profiles, pebble counts, velocity, temperature, chemistry, turbidity, and aquatic macroinvertebrate counts. The monitoring protocol for each–which Stream Team volunteers are trained in every outing morning–are described below as provided by Stephie Novak, WEN Stream Team coordinator (October 21, 2024).

Ten sites, two upstream and eight downstream of the dam site along Rattlesnake Creek were identified at the beginning of the project in 2017. Each year, photos and GPS points were used to ensure monitoring at sites remained consistent. Site information and summary of the vegetation, general morphology, and weather conditions were also reported as part of the monitoring protocol.

Upstream and downstream cross-sections were delineated at the same locations every year using the site guide (including photos and GPS points). All additional data was collected between the two established cross-section locations. The cross-sections were set up at least 50 feet apart with each delineated by a levelled and tightened string and tape measure attached at bankfull level across the stream. The measurement protocol for cross-sections is as follows: the width of the stream is divided into 20 to 50 intervals, the distance from the stream bed to the string (bankfull depth) and water depth are recorded for each interval with a stadia rod to the nearest 0.5 inches. Additional measurements are recorded for the wetted edges on each bank. If the measurement is taken on top of a rock and causes the stadia rod to be above the water, the measurement is marked with an “R”.

A pebble count was conducted between the two cross-section locations from left to right bankfull following Wolman’s (1954) procedure. Samplers walked diagonally across the stream and every two steps looked away (to avoid bias in substrate selection) and picked up the rock closest to the tip of their right wader. The rock’s intermediate (b) axis was measured using a gravelometer or less commonly, a ruler. The samplers called out the measurements to be recorded by someone at the bank and the process continued until at least 100 samples were collected. For mud and sand, a value of <4 mm was recorded and for rocks larger than the gravelometer, >300 mm was recorded.

Velocity was measured using a tennis ball thrown upstream, each starting at different distances from the bank. The time the tennis ball takes to travel from the upstream cross-section to the downstream cross-section was recorded for at least 10 trials. The distance between the cross-sections and the average time was recorded to calculate the surface water velocity as the average tennis ball travel time divided by the distance. To estimate stream velocity, the surface water value was multiplied by a coefficient of 0.8 to account for surface water having a higher velocity than the rest of the stream. Finally, discharge was estimated from the product of the average velocity, average water depth, and average wetted edge distance for the two cross-sections.

For temperature, three thermometers were set out to collect ambient air temperature (°C). Once this value was recorded, the thermometers were held under water at approximately one quarter of the distance into the stream from the bank. After submerging for at least 30 seconds, the thermometer was quickly pulled out, immediately read, and the temperature (°C) recorded.

For pH, six glass vials were rinsed out with water from the stream. Then, each vial was filled up to the 5 milliliter line with stream water. While wearing protective eyewear and gloves, volunteers added three drops of pH reagent for the normal range

https://doi.org/10.5194/egusphere-2025-6128
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test to three of the water samples and mixed by inverting. Five drops of the high-range pH reagent were put into the remaining three samples and also mixed by inverting. After being capped and resting for several minutes, the resulting colored liquid was compared to the pH key and the corresponding pH value was recorded for each trial.

To measure dissolved oxygen (DO), a specific DO bottle was brought into the stream to a section with no unusually still water or heavy ripples and rapids. Facing upstream, the DO bottle was submerged until it overflowed, and all air escaped the bottle. The stopper was inserted underwater to ensure no air bubbles were in the bottle. If air bubbles were present in the sample, it had to be retaken. While wearing gloves and protective eyewear, volunteers opened the DO Reagent 1 and 2 powder pillows and poured them into the water sample one at a time, ensuring all the powder entered the sample. The stopper was then put back in place and the bottle was inverted multiple times to mix the reagents. The solution sat until the precipitate settled to approximately half of the bottle. The bottle was inverted again, allowed to precipitate a second time, and then mixed a third time before being unstoppered for a third powder pillow to be mixed in. After re-stoppering, the bottle was vigorously shaken until no precipitate was left and the powder was fully mixed. The sample was then poured into a measuring vial and then into a square vial. The square vial was placed on a sheet of white paper to improve color differentiation, and the titration solution (sodium thiosulfate) was added one drop at a time, counting each number of drops and mixing between drops by swirling. When the solution was clear, one more drop of titrant was added. If the last drop did not improve transparency, the volunteer recorded the original number of drops; if it did improve clarity, they recorded the total number of drops. Each drop represents one mg/L of DO, so the number of drops was recorded as mg/L of DO present in the stream water sample. Two more DO measurements were made with new water samples using the same process. Then, the percentage of saturated oxygen was calculated based on the water temperature and mg/L of DO.

For aquatic macroinvertebrate counts, a net was placed on the river bottom downstream of the volunteer's position with the D-ring net opening facing upstream. The stream bed was vigorously kicked for 45 seconds. Then, the nets were brought to the bank where the macroinvertebrates were removed from the net into a tub. Multiple collections were made, each approximately twenty feet apart in the stream. At the bank, macroinvertebrates were sorted by taxa (generally family or order) using a dichotomous key and placed in ice cube trays with the same taxa for separation and counting. The macroinvertebrates were also separated by size to avoid larger macroinvertebrates consuming smaller ones. This procedure continued until at least 300 macroinvertebrates were sampled and sorted into taxa. After the required sample size had been completely documented, the macroinvertebrates were released back into the creek.

3.2 Data selection, compilation, and cleaning

WEN created fill-in-the-blank paper datasheets for each data type collected by Stream Team volunteers. The forms include date, names of volunteers, instructions, number of trials, and information relevant to each data type. Datasheets were filled out and collected at the end of each Stream Team outing. Winter season WEN volunteers later entered the data into Excel

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workbooks for each site, with a sheet for every paper datasheet and corresponding cells for the information collected (i.e., a block of cells designated for entering each pebble's b-axis on the pebble count sheet). Each cell is color-coded and labeled to ensure information is placed in the correct place. Cells not intended to have data entered are filled with black to ensure data goes in the correct place. Calculations are automated, including a stream quality metric from the macroinvertebrate count, a histogram of pebble count data, velocity measurements, and data averages. Any additional information was recorded as notes. WEN staff verified that the Excel workbook and physical datasheets had the same information.

To address research question 1, 'how has Rattlesnake Creek changed since the dam removal in 2020', we analyzed cross-sections, pebble counts, and aquatic macroinvertebrates as these characteristics have been shown to change post dam removal (Hart et al., 2002; Maloney et al., 2008; Orr et al., 2008). Previous studies have also found sediment transport and geomorphology to vary greatly depending on stream characteristics (East et al., 2018; Hart et al., 2002). Because the dam sluice gates were permanently opened in 2012, allowing most streamflow to travel unimpeded downstream, we didn't expect to see changes in water properties like chemistry, temperature, or turbidity, and chose not to analyze these data in the present study.

3.3 Data analysis

To analyze the data in RStudio (Version 2025.09.2), we extracted values from the sheets in the Excel workbooks and put them in CSV files organized by site, year, and datatype that could be read into the program. Further cleaning was done in R to remove spaces before and after data and establish all data entries into a single column in the workbook. Missing data and obvious data entry errors were cross-checked with WEN to ensure all data were included and there weren't entry errors from the physical datasheets. Unfortunately, the cross-section profiles had substantial missing data until 2021. Thus, we chose to only analyze pebble counts and macroinvertebrates, as both datasets were mostly complete.

To analyze the pebble counts, we plotted grain size distributions for each site for every year and calculated the median grain size, D_{50}; the 84th percentile grain size, D_{84}; and the 16th percentile grain size, D16, as described by Wolman (1954) and others (e.g., Kibler et al., 2011).

To quantify stream health from macroinvertebrate data, we used the Water Action Volunteers (WAV) Biotic Index, a water quality index developed for Wisconsin streams that classifies taxa of macroinvertebrates based on how pollutant tolerant they are (WAV, 2023). This biotic index was adapted from the Hilsenhoff Biotic Index (HBI), which identifies organisms down to genus or species (Crall et al., 2011). Because species identification is not always possible in the field and difficult for citizen scientists, Wisconsin scientists from the Department of Natural Resources and the University of Wisconsin-Madison designed the WAV Biotic Index to align with the HBI, but with less taxonomic resolution (WAV, 2023). While this index was designed for use in Wisconsin streams, the taxa included in this biotic index are the same as the taxa monitored by WEN. Because the

https://doi.org/10.5194/egusphere-2025-6128
Preprint. Discussion started: 2 January 2026

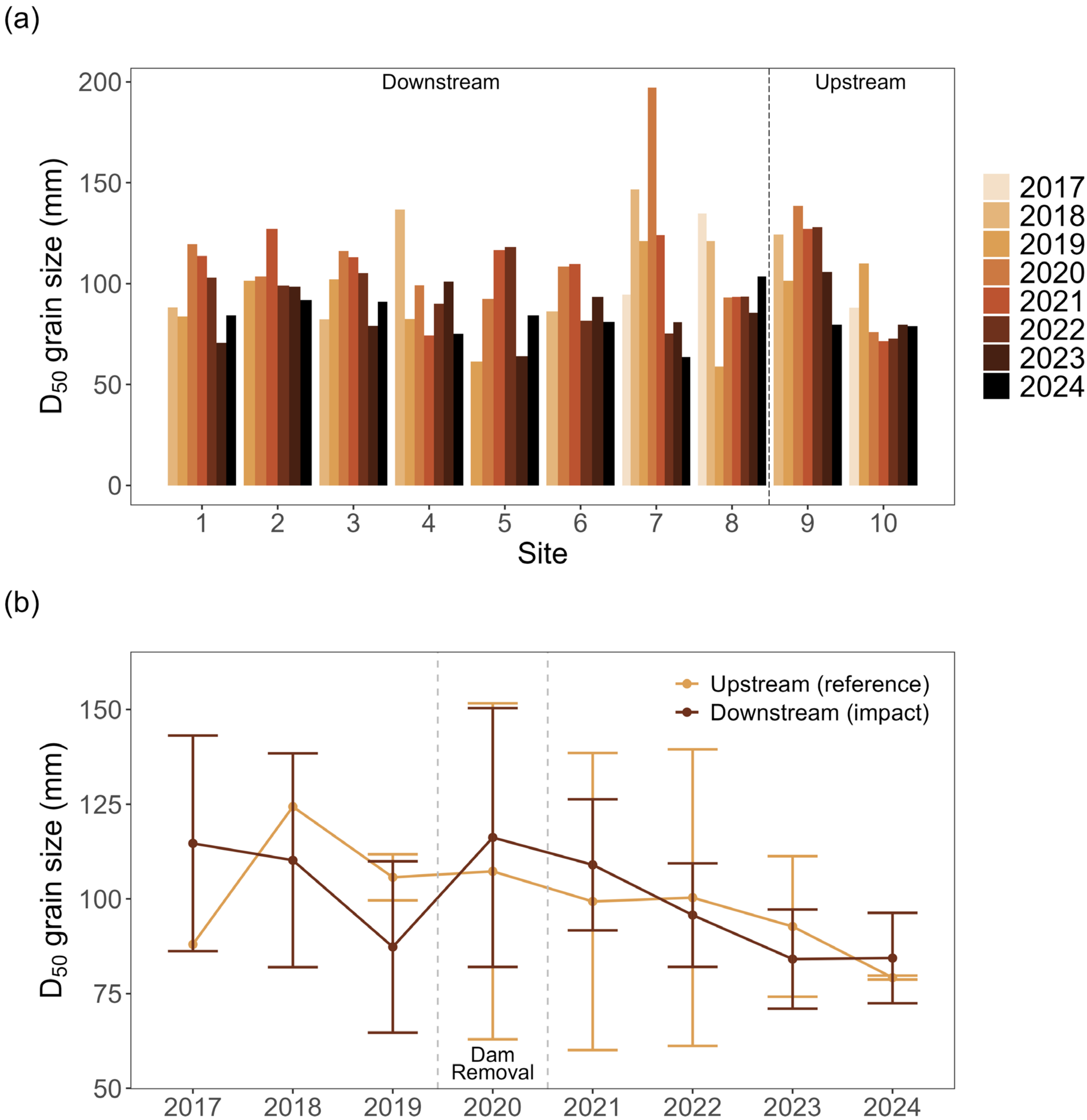
taxa are the same and the application is for citizen science-based stream monitoring, we determined that the WAV Biotic Index is appropriate to use for the present study's macroinvertebrate data.

This study uses the concepts developed for assessing the impacts of dam removal, including before-after-control-impact (BACI). BACI is a method that takes control sites and impacted sites to quantify change related to a time-specific event. For the present study, BACI is used to compare upstream and downstream reaches of this section of Rattlesnake Creek. Upstream sites are used for comparison (reference sites) as the characteristics from the upstream locations should not change post–dam removal (Conner et al., 2016; East et al., 2018; Orr et al., 2008; Smith 2002). We used the BACI approach to quantitatively evaluate if the difference between upstream and downstream variables changed after the dam removal. We calculated the mean value for each variable for every site above the dam and below the dam to calculate the difference. We did not include data collected in 2020, as data for some sites was collected during the dam removal and some was collected after. Due to the small numbers of observations, especially for the reference sites, descriptive statistics were used for this analysis.

4 Results

To address research question 1, ‘how has Rattlesnake Creek changed since the dam removal in 2020’, we conducted a comparison of pebble counts and biotic index values upstream and downstream of the dam site from pre– to post–dam removal datasets. From 2017 to 2024, pebble count median grain size data show no discernible trend (Fig. 2). Similarly, our calculated WAV Biotic Index shows no discernible trend in the distribution of taxa present across sites and years (Fig. 3). For both grain size and macroinvertebrate data, sites 7–10 were used to compare the data immediately upstream and downstream of the dam site from pre– and post–dam removal. We found no significant change in the difference between the reference and impact sites with respect to the grain size percentiles, nor with respect to the WAV Biotic Index.

https://doi.org/10.5194/egusphere-2025-6128
Preprint. Discussion started: 2 January 2026



285 Figure 2. Median (D_{50}) grain size distribution data. Top chart (a) shows D_{50} distribution by site for all monitoring years. The location of the dam, between sites 8 and 9, is depicted with a dashed line. Bottom chart (b) shows the average D_{50} distribution from before to after dam removal (2020; grey bar) for impact and reference sites. Data points without error bars are those with only one measurement documented.

https://doi.org/10.5194/egusphere-2025-6128
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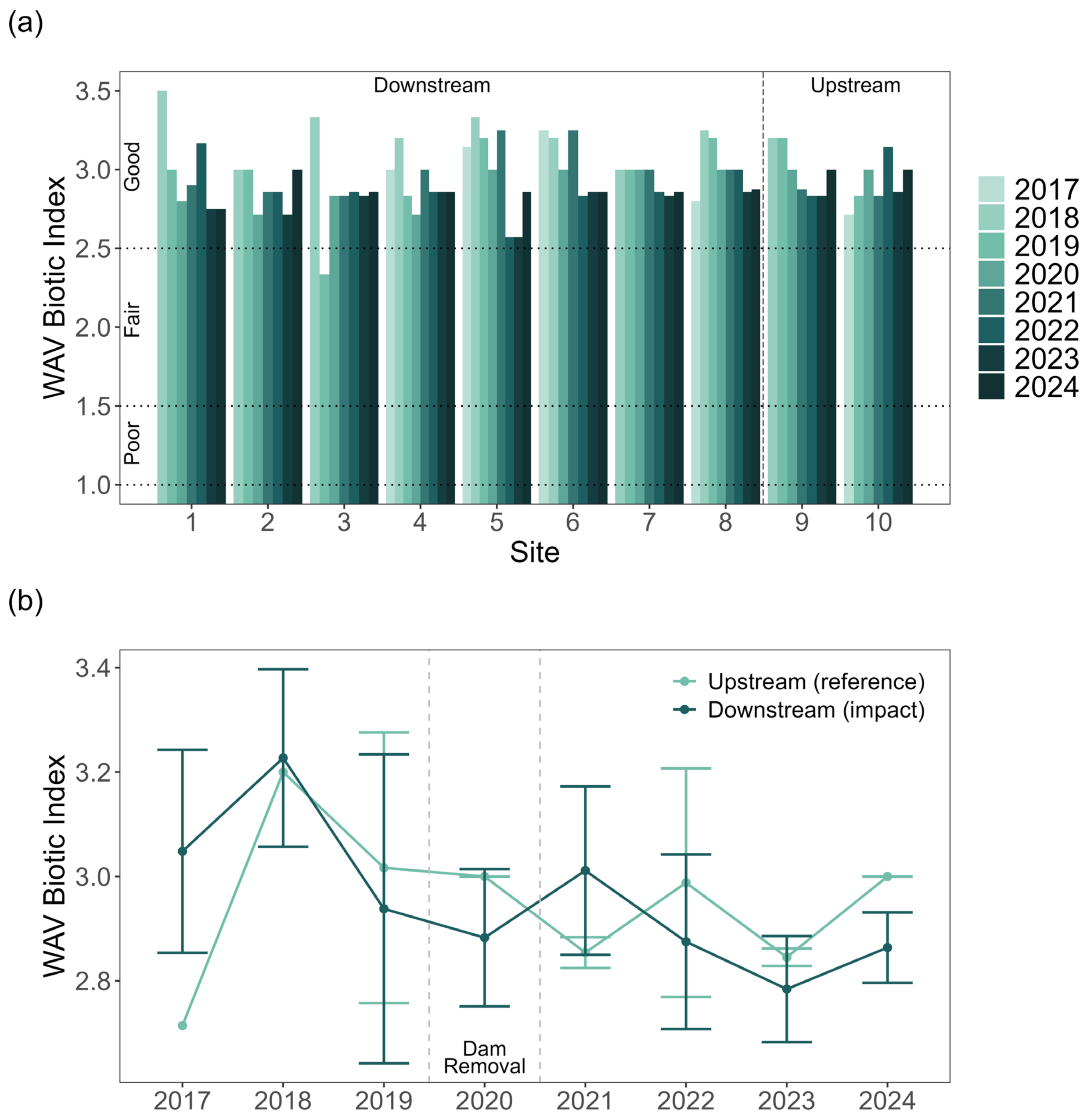

290 Figure 3. WAV biotic index data from macroinvertebrate counts. Top chart (a) shows WAV Biotic Index distribution by site for all monitoring years. The location of the dam, between sites 8 and 9, is depicted with a dashed line. Below (b) shows the average WAV Biotic Index distribution from before to after dam removal (2020; grey bar) for impact and reference sites. Data points without error bars are those with only one measurement documented.

https://doi.org/10.5194/egusphere-2025-6128
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To address research question 2, 'can citizen science projects effectively monitor local streams?', we must consider the completeness and usability of the data collected by WEN volunteers. Of the three datasets identified as the most relevant for assessing the impact of the dam removal project on Rattlesnake Creek, one dataset (cross-sections) was not usable. However, the citizen science data collection protocol yielded eight consecutive years of data for pebble counts and aquatic macroinvertebrate taxa that were complete and viable for our analyses. For these datasets, this demonstrates the efficacy of citizen science endeavors for long-term stream monitoring. The unusable, incomplete, cross-section dataset can instead provide insight on where to make improvements in the data collection protocol.

5 Discussion

A fining in the median grain size downstream post–dam removal and a transition to upstream and downstream reaches having similar grain sizes would indicate restored movement of sediment past the dam (East et al., 2018; Lu et al., 2022; Magilligan et al., 2021; Potyondy & Hardy, 1994). For macroinvertebrates, a decreasing WAV Biotic Index downstream would indicate a decrease in stream health and increase in pollution, while an increase in the index would indicate an increase in stream health and decrease in pollution (WAV, 2023).

Our results span three years before the dam removal to four years after and demonstrate no significant shifts in grain size, indicating that the removal of this dam on Rattlesnake Creek caused minimal impact on sediment flow downstream. The discharge record from the MDNRC gaging station shows that the two years prior to dam removal had higher maximum flows than the two years that followed removal (~32 m^3/s in May 2018 and ~29 m^3/s in May 2019 versus ~21 m^3/s in June 2021 and ~25 m^3/s in June 2022), however the maximum flow in 2023 was much closer to that of 2018 (~30 m^3/s in May 2023). Interpreting the lack of change in the sediment distribution requires considering the possibility that flows were insufficient after the dam removal to entrain and transport much bedload. Furthermore, irregular variation from year to year can also be due to user-dependent bias from mistakes in measuring and biased selection, which have been shown to increase as different observers collect data (Downs et al., 2021; Marcus et al., 1995). However, year-to-year data from professional science also has substantial variations (Crall et al., 2011; Kosmala et al., 2016).

Similarly, macroinvertebrate diversity, frequently used as the biotic indicator of stream health, showed no discernible trend from before to after the dam removal. Rattlesnake Creek, in particular the reaches within this study area, is heavily used for recreation. From children building rock piles to kayakers moving woody debris, there is an unquantifiable human impact that must be considered with respect to both sediment transport and macroinvertebrates in this area. Finally, at the time of the dam removal, the sluice gates had been open for eight years, so perhaps data collection before and after this opening would have revealed some change in sediment transport and macroinvertebrate populations downstream. Strongly considering the role of the opening left behind from the removal of the sluice gates, the findings from our data suggest that the removal of a small dam with a large opening in the center does not impact sediment transport or aquatic macroinvertebrate populations on the scale of years. However, for these two datasets, it is important to recognize that the Stream Team volunteers collected substantial usable data for monitoring baseline stream health.

Stream Team citizen scientists include students, professionals, families, and retirees. Anecdotally, people love identifying the bugs, walking in the creek, and connecting with their environment (Fassnacht, March 30, 2025). It gives members of the community the chance to learn things, collect valuable data, and work without stress or a "traditional education" background knowledge requirement. Rattlesnake Creek is a popular recreational area, and hikers walking by love stopping and seeing what bugs Stream Team has found and ask what the volunteers are doing in the creek (Fassnacht, March 30, 2025). Volunteers, in turn, get the opportunity to share what they're doing and invite the hikers to join next time.

WEN's Stream Team program also teaches people that science is approachable and helps them build camaraderie with like-minded people in their community, solving problems on the fly, and pointing out the wildlife, rocks, and bugs. Previous studies have similarly found that participating in citizen science is an effective way of introducing environmental science as something that is approachable and understandable (Ardoin et al., 2019; Bonney et al., 2016; Novacek, 2008)

6 Limitations

To analyze the impacts of the dam removal, we had intended to compare upstream and downstream cross-sections over time, as these data would have given us insights on how the dam removal impacted the geomorphology of the stream (Magilligan et al., 2021). Unfortunately, cross-sectional data was not usable, as the dataset was incomplete in multiple ways. The two major missing data issues for the cross-sections were related to measurement locations and location labeling. Most water depth and bankfull data were recorded, but almost every dataset before 2021 was missing the measurement increments across the stream, making it impossible to discern where the elevation and water depths were taken. For each site, the protocol requires the measurement of two cross-sections: one upstream and one downstream, marking the boundaries for all other data collection. Unfortunately, though datasheets provide evidence that two cross sections were measured, identification of which cross-section was upstream and which was downstream was frequently not recorded, making year-to-year comparisons between them impossible.

Data consistency was also limited because both physical and digital datasheets varied over time with revisions as both Stream Team coordinators and the volunteers changed over time. Fundamentally, and specifically for the cross-section data, a lack of in-situ verification of complete data collection and accurate data recording before leaving the site at the end of Stream Team field days led to substantial missing data.

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7. Conclusions and future work

We found no evidence of a change in stream sediment size or macroinvertebrate diversity following the removal of the Rattlesnake Creek dam. We believe there are many contributing factors to this lack of change, emphasizing the unimpeded flow through the open sluice gates for eight years prior to dam removal and potentially including lower discharge after dam removal as well as the ongoing recreation activities in the stream. We do not attribute the lack of change in these variables to a lack of quality of the citizen scientist –collected data of sediment size or macroinvertebrates.

Citizen science data that was collected consistently over time was helpful for monitoring the stream when it was recorded completely and correctly, which was the case for some (e.g., sediment size and macroinvertebrates), but not all (e.g., cross-sections), datasets. Based on the extensive data compilation and cleaning prior to analysis, we have identified four 'best practices' for improving citizen science data collection for use in scientific analysis: 1) ensure everything that needs to be recorded has a place in the datasheet for recording it and verify that the data has been collected before leaving the field; 2) design digital datasheets so that it is clear where data needs to be entered and makes it easy to do so for volunteers; 3) keep data in one column or row for the same data (i.e. keep all pebble count measurements in one column); 4) create an easy-to-access location for the data, such as a summary page, where the data can be read by a coding language to do the analysis.

Finally, future work should include an examination of the completeness of the data not analyzed in this study, which includes all the stream chemistry measurements, temperature, velocity, and turbidity.

Data availability

The citizen science data that supports this research are online at 10.6084/m9.figshare.30752828 (Blakey et al., 2025a, last access: 1 December 2025).

Interactive computing environment

Quarto R files for the analysis and plotting of this data are available at 10.6084/m9.figshare.30758267 (Blakey, 2025b, last access: 1 December 2025).

Author contribution

BB, in collaboration with WEN, conceived the experiment and designed the research protocol. The manuscript was written by NB and BB. BB created the figures. BB and NB discussed the results and manuscript narrative as well as contributed to the editing process.

Competing interests

The authors declare they have no conflict of interest.

Ethical Statement

This research uses data collected by citizen scientists but does not use data on the citizen scientists themselves. All citizen scientists were voluntary participants in contributing stream monitoring data and signed consent forms at the beginning of each Stream Team monitoring season (on their first data collection outing).

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