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Impacts of Stream Habitat Restoration on Macroinvertebrate Assemblages: A Systematic Literature Review

Morgan E. Seitzer
Portland State University

Impacts of stream habitat restoration on macroinvertebrate assemblages: A Systematic Literature Review

by

Morgan E. Seitzer

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Yangdong Pan

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Abstract

Globally, river restoration has become a popular tool for improving the health of a watershed and restoring ecosystem services, but still has significant knowledge gaps. In certain areas and scientific communities, special attention has been given to the response of macroinvertebrates as a measure of restoration success. This systematic literature review aims to highlight and discuss the patterns in studies that have comparable before-and-after restoration data on macroinvertebrates after reconnecting stream channels to their floodplains. Macroinvertebrate sampling is a simple if not time-consuming task that can reveal important data about habitat quality. Because they serve as an important food source for salmonids, this data is especially relevant in the Pacific Northwest, where many species of salmon are listed as either Threatened or Endangered, and improving habitat for salmon is often a goal of river restoration projects. This literature review using the PSALSAR method found that the majority of stream restoration took place in the watershed with agricultural (52%) or urban (21%) land-use type. Restored stream reaches varied from 0.4 to 11.5 km with an average of 2.8 km. Of the nineteen studies that analyzed macroinvertebrate metrics, 73% of those show a positive response to restoration. Environmental managers should incorporate biological indicators as defined measures of success during the planning phase and continue monitoring for at least ten years post restoration. My research concludes that restoration of streams to their historic floodplains is often beneficial for macroinvertebrates, and by extension, many other parts of the local ecosystem.

Introduction

The Processes of River Restoration

Valley floodplain restoration projects seek to restore not a single-threaded channel stream, but an entire connected system. This scale of change to the landscape induces hydrogeomorphic processes that have been shown to enable the riverine system to recover to pre-disturbance conditions (Flitcroft et al., 2022). One of the ways this scale of change is induced is by filling previously single-threaded, sometimes incised channels with a natural material. This raises the lowest level at which the incoming head waters can flow, and effectively raises the entire stream bed (Flitcroft et al., 2022). The hope of raising the stream bed is that new channels will be formed when the water must flow in new directions. By re-creating a sinuous, multi-threaded floodplain, more permeable surface area is able to be inundated with the incoming waters (Cluer & Thorne, 2014), which helps reduce the amount of time that smaller pools and streams will be seasonally dried. This effect has been seen to support vegetative growth year-round, providing refuge and habitat for aquatic organisms (Flitcroft et al., 2022), as well as support hyporheic exchange (Hester & Gooseff, 2010).

Restoration of floodplains helps to create variation of habitat sub-type within the system. Some major classifications of those habitat sub-types are riffles, pools, and off-channel habitats (Landers, et al. n.d.). Riffles are often shallower, faster moving sections of the stream that mix oxygen into the water. Pools are deeper, wider sections that are often formed when a riffle curves into the landscape and removes sediments from the bank. Off-channel habitats are those that are only temporally connected to the stream, or during certain seasons (Landers, et al. n.d.). Studies have seen riffles to be a dominant habitat type in valley floodplains, even amongst varying levels of habitat quality (i.e. reaches that were restored, in transition, and unrestored) (Edwards et al., 2020), with unrestored reaches seeing the highest ratio of riffles to other habitats (Edwards et al., 2020). The restoration of meandering streams encourages the formation of pools and is important to providing calmer areas of water for salmon smolt and macroinvertebrates to rest.

These combined changes constitute restoration to a “Stage 0” state, or, one that reflects conditions prior to anthropogenic influences (Cluer & Thorne, 2014). These changes are important to understand, as macroinvertebrates play a key role in the stream ecosystem, often acting as a primary food source for anadromous fish species which are in decline throughout the west coast.

Macroinvertebrates, Salmon, and the Cultural Relevance and Importance of River Restoration

The community makeup of benthic macroinvertebrates is influenced by a multitude of factors based on the unique chemical, physical, and biological factors of the stream habitat they reside in (Plotnikoff, 1998). Often one of the goals of stream restoration involves the reconnection of a disconnected, channelized, or otherwise degraded stream channel with its historic floodplain. Restoration events change the hydrogeomorphic processes and thus habitat conditions of the stream and likewise can change the macroinvertebrate community drastically (Obolewski et al., 2016).

Anadromous fish are species that spend at least some part of their life cycle in fresh and salt water and includes many culturally and ecologically important species in the western coast of the United States. In the Pacific Northwest this includes Chinook, Coho, and Sockeye salmon, as well as steelhead and bull trout (Angeles & Us, n.d.). Over these fish's life history, they perform different functions within the food web. In their birth streams as spawned eggs, they can be a nutrient-rich food source to small fish. As fry they move to side-channels and lakes, relying on slower water to move more efficiently, and some are eaten by larger fish, but others live and consume small insects and algae within their waterbodies (Angeles & Us, n.d.). The anadromous fish then spends a period of time in the ocean before returning inland to freshwater streams as part of a larger spawning migration. Once the females have released their eggs and the males have fertilized them, they will eventually all die, and become a large nutrient source for the waterway (Angeles & Us, n.d.).

Prior to European colonization of the area, the Indigenous peoples in Oregon relied on salmon travelling the Columbia River for sustenance and cultural uses (Marshall, 2006). Salmon is a First Food, and part of a religious ceremony performed by tribes in which special recognition for the animal is placed. Interviews done with Indigenous knowledge holders (Elders) in British Columbia indicate that not only do those communities view threats to salmon as equally as threats to human well-being, but that the relationship between salmon and people is being changed (Reid et al., 2022). Because of the current power-dynamics between Indigenous peoples, whether or not their sovereignty is recognized, the restoration of these species is an especially pressing environmental justice issue.

One such way to tackle this issue is with river restoration. River restoration is a subset of the environmental restoration field, and typically involves bank stabilization, stream re-meandering, removal of invasive species, installation of large woody debris or boulders, or sediment removal if historical dumping of fill material took place, or if the backfill from dams is especially contaminated. All of these restoration methods will end up changing the chemical, biological, and/or physical habitat of the river in some way, but the end goal is typically to restore ecosystem services (Verdonschot & Verdonschot, 2023). These services include nutrient cycling, wastewater treatment, production of crops via irrigation, drinking water, transportation, and travel amongst others.

Macroinvertebrates require similar habitat conditions to anadromous fish, such as cooler temperatures and lower conductivity. They make up an important trophic level of the benthic ecosystem, consuming algae, leaves, and bacteria, but also being consumed by larger organisms such as amphibians, fish, and birds (Wallace & Webster, 1996). They have various community compositions that have the potential to fill overlapping environmental niches while co-existing, and their presence can be an indication of a healthy ecosystem (Wallace & Webster, 1996). Because they are a major food source for the endangered Pacific salmon (Plotnikoff & Polayes, 1999), this makes river restoration a potentially valuable tool to restoring both habitat conditions and food resources for the salmon and vulnerable macroinvertebrate populations. Slower flowing segments of streams and rivers called pools, and environmentally heterogenous off-channel habitats provide excellent grounds for these weaker swimmers, and function as nursery areas for recently spawned salmonids. These off-channel and side habitats are often formed in wet valley habitats and provide invaluable refuge for macroinvertebrates throughout the year by maintaining a diversity of habitats that can be taken advantage of (Mathers et al., 2022). During flooding events these channels are temporarily connected, allowing for genetic diversity to flow between sections of the floodplain and maintaining community resiliency.

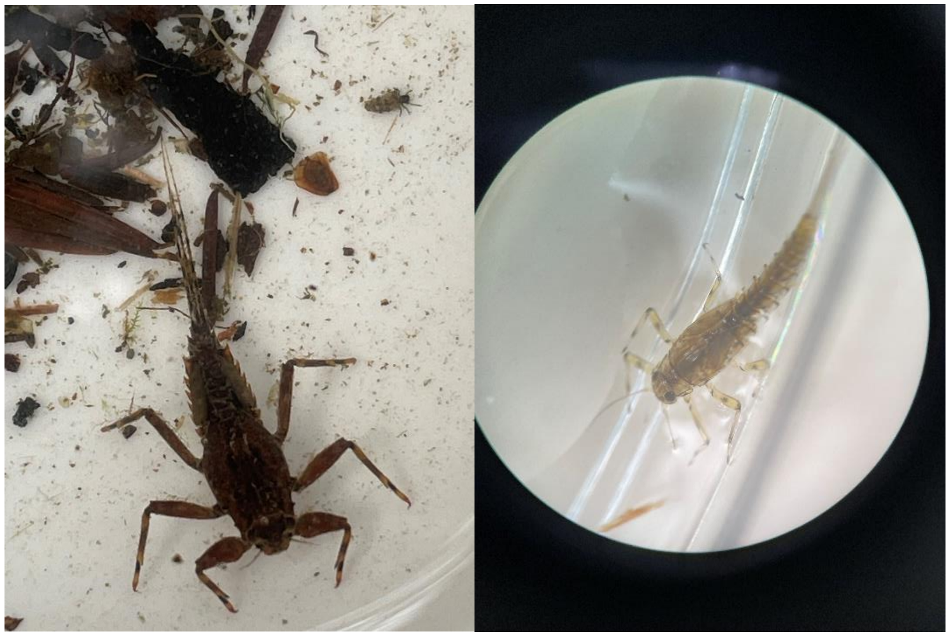

Figure 1: Mayfly (Ephemeroptera) larva.

One of the factors of a watershed that can affect many of its biologic and chemical properties is its connectivity. The lateral hydrologic connectivity (LHC) of a riverine system refers to how the intermittent rising and falling of water levels that periodically connects nearby channels and results in the exchange of sediments, nutrients, and importantly, different organisms. The degree to which a system is laterally connected can influence the speed that water flows, its temperature, how quickly nutrients settle, and the makeup and dispersal of macroinvertebrate assemblages (Kang & King, 2013). One recent study found that increased LHC was positively correlated with macroinvertebrate density and richness, but not diversity (Larsen et al., 2019). As waterways become connected, disconnected, and reconnected, the physical environment is changed and a more diverse habitat is created (Larsen et al., 2019). A more diverse habitat lends itself to being able to be colonized by macroinvertebrates of various environmental niche and establishes a more stable food web.

The varied forms of stream restoration

In order to understand the effects that restoration projects can have on the aquatic ecosystem, a short background of the methods and project types will be discussed. When engineers, scientists, city officials, and communities come together to design a stream restoration project there are factors to consider that can influence the methods employed, the specific area restored, and the goals set. These factors will dictate how a project is completed and are what make each project unique. This review will not go into the monetary factors of stream restoration, but it should be noted that it is a key part of the decision-making process.

Among the reasons why a stream may be undergoing restoration is improving the aesthetic appearance of the area, improving fish passage, modifying the flow regime to reduce flooding and stabilize bank erosion, or removing outdated dams (Wohl et al., 2015). Many projects encompass one or more of these goals, or by achieving one goal, another is additionally accomplished. For example, a city setting a goal to improve fish passage in an urban stream may alter the habitat in a manner that also improves the overall aesthetic appearance of the area. A project designed to remove heavy metals from an abandoned mining operation in order to improve water quality may have the added benefit of allowing for more sensitive species to return to the area.

The approach to the type of restoration performed and the specific goals set may also be influenced by the history of the land-use of the area. If a wetland was drained and heavily channelized in order to create agricultural fields, a goal may be restoring ecosystem services to the area. When land is heavily used for agricultural purposes for a long period of time, silt, pesticides, and herbicides can accumulate in the channelized streams due to runoff from the fields (Ntow et al., 2008). This accumulation of silt can cause habitat homogeneity and loss of spaces for macroinvertebrates to hide and forage, leading to biodiversity and abundance loss (Leitner et al., 2023).

Another factor to consider is the order of the stream being restored. Stream order refers to the number of tributaries that flow into that particular segment of stream, and there are two proposed classification types for determining stream order: the Strahler method, and the Shreve method. For this paper, I will be using the Strahler method for classifying streams. Both methods refer to streams on the *outermost* reaches of the watershed, sections that bubble from the ground and have no other tributaries flowing into them, first order streams. In the Shreve method, when two first-order streams meet it becomes a second-order stream, then a third-order stream, and so on (Shreve, 1967). First-order streams are more likely to be small, and generally less impacted by human activities due to not having upstream water to contaminate it. As stream order increases, stream size typically increases as more tributaries are connected to a larger body. In this review, the largest stream restored was a ninth order river, the Rhone in France, which is a major river in Europe.

Finally, one of the major considerations made in restoration that will be examined in this paper is the length of the waterway that has been restored. For the purposes of my review, I specifically sought studies whose goal was floodplain connectivity, wherein the design for the restoration was connecting streams, channels, or disconnected areas back to a larger system. Examples of a smaller-scale project could be removing the invasive species in a city park, or removing a small, outdated dam. Some projects, such as bank stabilization via planting native plants, can occur on the scale of just a few feet, but can also be implemented on the magnitude of miles. A study done with restoration managers in the Southwest region of the United States found that of over 570 projects, most of them were < 3 kilometers (1.86 miles) (Follstad Shah et al., 2007).

Research Questions, and the Example of Whychus Creek

This systematic literature review (SLR) aims to evaluate and describe the current trends in restoration success amongst published research, identify areas of knowledge gaps, and to attempt to answer the following questions:

1. How do macroinvertebrates respond to river restoration when successful floodplain reconnection is achieved?
2. What patterns of successful restoration projects emerge from the current literature?

These questions were posed and compared to the Whychus Creek restoration project started in 2016 at the Whychus Canyon Preserve and Rimrock Ranch. This project is located in central Oregon and was recently completed in 2023 (OWEB, 2023). The once heavily altered floodplain has undergone numerous projects aimed at restoring it to a “ 0” condition. Stage 0 refers to the state at which the ecosystem existed prior to anthropogenic influences altering it (NPS, 2024). Through the combined efforts of over a dozen organizations, state departments, and local stakeholders, the valley has been reconnected to a degree that allows for the historical summer flow of water to return, providing more habitat for salmon. The restoration has also seen an increase in the diversity of macroinvertebrates at the site, notably in the side and off-channel sections of the stream (Noone, 2023, OWEB, 2023). It's this kind of habitat restoration, where the goal is floodplain connectivity, and the project studies the effects on macroinvertebrates, that I researched in my study. Within the practice of stream restoration there are also numerous techniques that can be applied. These techniques often have more than one purpose or desired end result. In this study, I aimed to only focus on projects wherein increased hydrologic connectivity was an outcome of the restoration, regardless of the techniques applied.

Methods

This thesis was conducted using the PSALSAR method (Mengist et al., 2020), in order to provide a detailed, reproducible systematic literature review. As described by Mengist et al. 2020, the PSALSAR method involves six steps.

Synthesized Literature Review: PSALSAR

Step 1. Protocol:

The "protocol" of this study is river ecosystems that have been restored via some form of floodplain connectivity. This can include re-meandering of streams that have been channelized, removal of small dams, and reconnection of oxbow lakes, amongst other restoration techniques. The goal of the study was to analyze the outcome of floodplain restoration and reconnection and the resulting creation of a more complex habitat type on the macroinvertebrate communities present.

Step 2. Search:

The initial data search utilized the following entries: "Any field" contains "macroinvertebrate assemblage", and "any field" contains "connecting stream to floodplain", and "subject" contains "restoration". Only peer-reviewed articles published between 2000-2023 were considered for analysis. Using the PSU Library advanced search function, this returns 48 results as of 11/13/2023. Microsoft Excel was used to maintain a log of the articles reviewed and categorize them as either "Yes" or "No" to being used in the review. This search only returned 2 useful studies for review, so a new search query was formed.

The secondary search also used the PSU Library website, and the new searches performed were “any field” contains “floodplain restoration”, and “subject” contains “macroinvertebrate”, and “subject” contains “restoration”. This search returned 147 articles as of 12/02/2023. Of this secondary search, nineteen of the articles were deemed usable for further analysis of their data on macroinvertebrates.

Search Criteria	Number of results	Usable results
“Any field” contains “macroinvertebrate assemblage” **and** “any field” contains “connecting stream to floodplain” **and** “subject” contains “restoration.” Years 2000-2023. Peer-Reviewed Articles	48	2
“Any field” contains “floodplain restoration” **and** “subject” contains “macroinvertebrate” **and** “subject” contains “restoration”	147 (87.08%)	19 (12.92%)

Table 1: Search terms for literature review and the resulting availability of data.

Step 3. Appraisal:

Studies were evaluated under a variety of criteria. Initially, the 147 studies from the secondary search were categorized as either “usable”, or “not usable” based on the following criteria:

1. Must be restoration in which the goal, or the result, was a form of measurable floodplain reconnection (examples: small dam removal, re-meandering, reconnection of oxbow lakes)
2. Results must measure macroinvertebrate response to the restoration OR be measuring against a reference river in post-restoration.

Unfortunately, 87% of the studies on restored streams were rejected because they did not measure a macroinvertebrate response to the treatment. This was identified to be an area with a significant knowledge gap when it comes to river restoration as a whole. Many of the studies measured metrics such as temperature, discharge rate, water quality, and depth, but also lacked observations of biological indicators of a healthy ecosystem, such as presence of flora and fauna.

Step 4. Synthesis:

All studies from the secondary literature review were added to an Excel document and further analyzed for relevance. The nineteen selected studies represented seventeen total river restoration projects (2 studies were further examinations of previously noted projects, but they provided new data on the macroinvertebrate communities, and so were included in the synthesis).

Link to Google Drive spreadsheets: PSALSAR Literature Review and Calculations

Step 5. Analysis:

Analysis of the data was conducted by calculating basic parameters such as averages and creating pivot tables and graphs to show data trends. The Shannon-Weiner Diversity Index, or Shannon index, was calculated for each of the habitat types sampled and represented at Whychus Creek. This metric was chosen because of its widespread use in ecology to describe the evenness of a community's species composition, or how diverse it is. An index score of 0 would indicate that only one species is present, whereas a higher score would indicate a more diverse ecosystem. Where available, the Shannon index from the literature was also compiled and averaged to present a comparison to Whychus Creek. The formula used for calculating this score was:

$$H = -\Sigma[(p_i) \times \log(p_i)]$$

H: Shannon Diversity Index

p_i: proportion of individuals of a species within the community (e.g. A community of birds may have 50 individuals and only 2 eagles, which would be represented as 2/50 = 0.04, or 4%)

Other metrics were chosen for analysis based on availability of data in the literature. These metrics are:

Length Restored: The total length of waterway reconnected to the floodplain via restoration.

Land Use Type: The way that the land surrounding the restoration site is being used, e.g., agricultural, power generation.

Stream Order: According to the Shreve method, refers to the relative size of a waterway based on how many branches flow into it. Lower order streams contain the source of the water and are called "headwaters". These flow into higher order streams.

Time Since Restoration: The number of years since the restoration project was completed.

Location of Sampling: Whether or not the study indicates if it sampled in a sub-habitat type including pools, riffles, and off-channel sites.

Macroinvertebrate responses as defined below:

Abundance	The unit number of individuals of a specific species in an area.
Biomass	A measure of the mass of living organisms per unit of an area (e.g., mg/cm^2). Can be defined by a group of organisms, a specific species, etc.
Density	The number of individuals of a specific species that appear per unit area.
Diversity	The number of unique species in a specific area is related to its abundance. In ecology diversity is often measured by the Shannon-Weiner diversity index, or Simpson's diversity index.
Richness	The number of species occurring in a specific area.

Table 2: Definitions of ecological measurements.

Step 6. Report:

The results of the literature review was used to write this report and disseminate the information via presentation to students and faculty at Portland State University. A slideshow was made available and presented with a voiceover to discuss the findings.

Results

Restored Streams

The most common land-use type of the restored streams was agricultural, which affected 52.6% of the areas studied, followed by urban use at 21%. Three of the studies involved removal of dams that had been used for power generation. Currently that represents approximately 14% of the studies, but as more dam removal projects happen (particularly in the Pacific Northwest) with pre- and post-monitoring of macroinvertebrate communities, more studies will hopefully become available. Removing dams can be an effective and relatively quick method of restoring salmonid spawning grounds (Harrison et al., 2018).

Of the seventeen waterways represented in this review, almost half of them (47.1%) did not indicate which order the stream was (Table 4). Of those reported, the most common was a first order stream (17.6%). Five of the restoration projects took place on smaller rivers and streams (1^{st} or 2^{nd} order), with the exception of two; one performed on a ninth order river, the Rhone in France, and one on an eighth order river, the Ebro in Spain. The majority of the restored area of Whychus Creek is a third-order headwater stream.

There was some variation when it came to the lengths of waterways restored. The longest segment of river or stream restored was approximately 4,000 meters, and the shortest only 400 meters. The average length of all recorded lengths of study areas restored was approximately 1,255 ±1,070 meters (Table 6). The project at Whychus Creek reconnected approximately 3,900 meters back to the floodplain, for an average restored length of 1,800 meters (Figure 2). Five of the lengths of the studies could not be quantified due to the complexity of the project, the number represented in a single study, or the lack of it being recorded.

The time since restoration completion of the studies ranged from only 16 months (1.33 years) to 25 years (Table 7). The average time since completion of sampling was 5.52 ± 1.2 years. There were 28 different data points for sampling times, and the median of these times was 3.5 years, indicating a slight skew towards shorter timeframes as more than half of the sampling was performed less than four years from the completion of restoration. This result highlighted the lack of long-term research being published on restoration outcomes in regard to macroinvertebrate response.

Macroinvertebrate Response to Restoration

Overall, macroinvertebrates displayed a mostly positive response to the various forms of river restoration (Table 3, Figure 2). The most commonly reported metric was richness, which increased in twelve of the fourteen studies (85.7%). Biomass was the least reported metric, possibly due to its time-consuming and arduous nature, and only four studies reported it. Of those four studies, three saw an increase, and one saw a decrease in overall biomass following restoration. Diversity had the most "neutral/mixed" responses, which may point to the variety of ways that macroinvertebrate community assemblage can change following restoration. Overall, however, of the 45 different indications of metrics gathered there was a 73% overall positive response to restoration from the macroinvertebrates studied.

The restored streams from the literature had an average Shannon-Weiner diversity index (when reported) of 2.66 ±0.82 (Table 8). Of the different measures of diversity, the Shannon index was the most commonly used within the selected literature, with six (31.6%) of the studies reporting the value for restored streams. However, many studies reported other indices, making a true comparison difficult.

Whychus Creek: A Case Study

Location of sampling at Whychus Creek was well detailed in Noone et al. 2023 by recording the habitat type (pool, riffle, or off-channel) and whether the area was restored, unrestored, or in a transition phase. In the studies synthesized, however, only six described the habitat type sampled, and of those only two took samples from "pool" type habitats. All sampled from riffles in off-channel and in the main channel of the projects. Of these six studies there were ten metrics reported that increased and four that remained neutral post-restoration. One study showed only neutral effects but sampled only within riffle areas upstream and downstream of a dam-removal project (Mahan et al., 2021).

Out of the nineteen studies used in the final systematic literature review, only six of those studies detailed the habitat type that the macroinvertebrates were sampled in. The major classifications fell into, or were comparable to, the classifications used by Noone et al. (2023) to describe locations of sampling as either "riffle", "pool", or "off-channel". Three of these studies only sampled macroinvertebrates within riffle type areas in order to standardize their collection method. The other three also sampled within riffles, but also sampled from pools, and two collected from runs.

At Whychus Creek, the data for total macroinvertebrates found at each sampling site and sub-site was compiled to calculate the Shannon-Weiner diversity index (Figure 4). The site with the highest Shannon index was the restored pools, with a value of 2.79. The lowest was the transitional riffles at 0.67. The pools consistently had the highest index value in each category at an average of 2.65 in the control sample sites, 2.79 in the restored sample sites, and 2.48 in the transitional sampling sites. Off-channel habitats were higher than riffle habitats in both restored and transition sites but were not measured in control sites. The average Shannon-Weiner index from the reviewed literature was 2.66 ±0.82, which overlaps with seven of the eight Shannon index values from the different habitat types at Whychus Creek. Only the transitional riffle had a score that fell outside the range of the average literatures scores.

Macroinvertebrate Reponses in Restored Area from 19 Studies					
	Abundance	Biomass	Density	Diversity	Richness
Increase	6	3	6	6	12
Decrease	0	1	0	0	1
Neutral/Mixed results	1	0	3	4	2

Table 3: Count of types of responses macroinvertebrates experienced due to restoration.

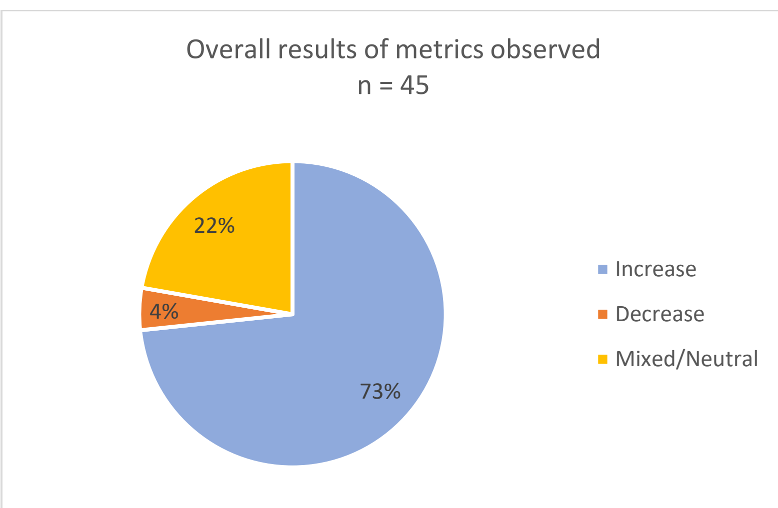

Figure 2: Percentages of macroinvertebrate community metrics “increase”, “decrease”, and “mixed/neutral” responses to restoration

Land Use Type	count
Agriculture	10
Timber	3
Power	3
Urban	4
Transportation/Travel	1
N/A	2
Total	23

Table 4: Summary of land-use types of the areas restored.

Stream Order	count
1^{st}	3 (17.6%)
2^{nd}	2 (11.7%)
3^{rd}	0 (0.0%)
4^{th}	1 (5.9%)
5^{th}	1 (5.9%)
$>5^{th}$	2 (11.7%)
n/a	8 (47.1%)
Total	17

Table 5: Summary of the stream orders represented in the studies.

Length Restored (m)	
Shortest	400
Longest	4,000
Average	1,255 ±1,070
Whychus Creek avg.	1,800
Ranges	**count**
<1,000 meters	6 (31.6%)

1,000<x <10,000 meters	8 (42.1%)
N/A	5 (26.3%)

Table 6: Summary of lengths of streams restored. "N/A" for streams where total length was not recorded or could not be quantified from the available study.

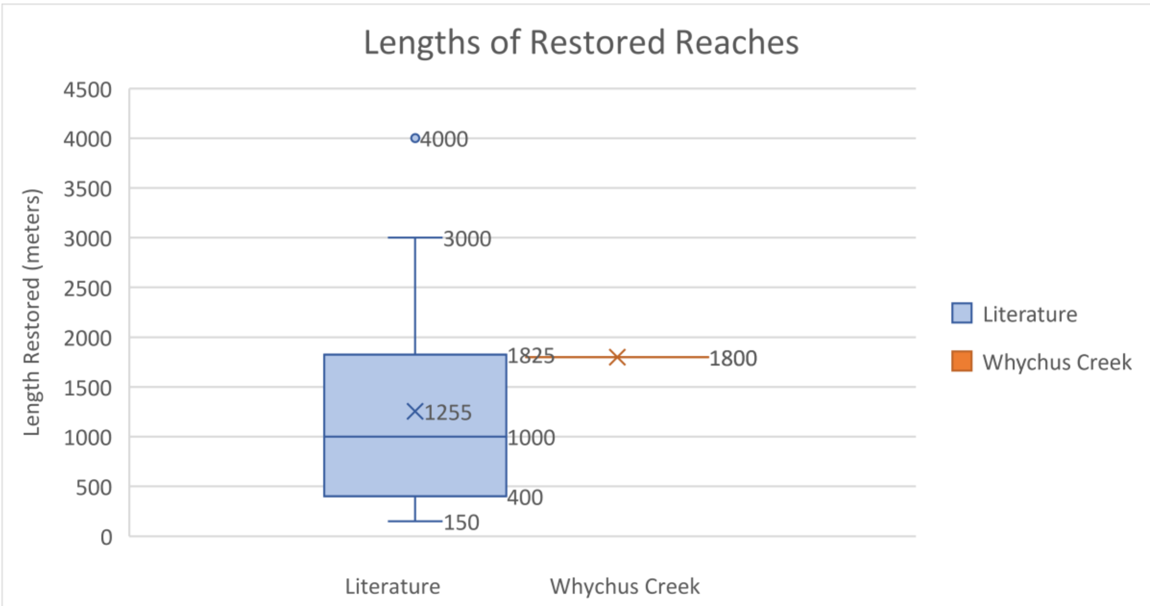

Figure 2: Box-and-Whisker plot of the lengths of restored reaches in the reviewed literature compared to the length restored at Whychus Creek.

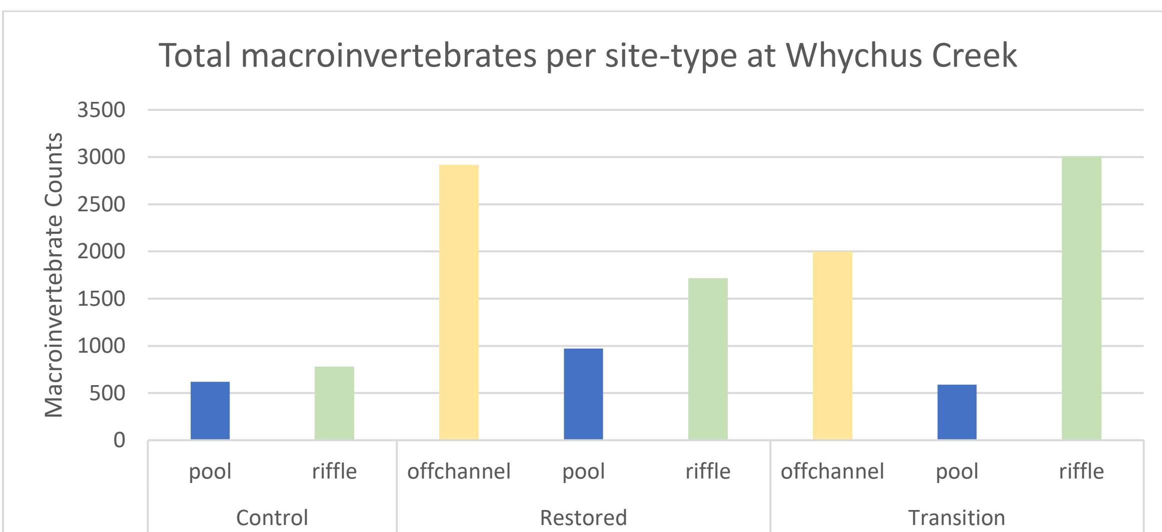

Figure 3: Bar plot showing the number of macroinvertebrates found in each sub-habitat type at Whychus Creek.

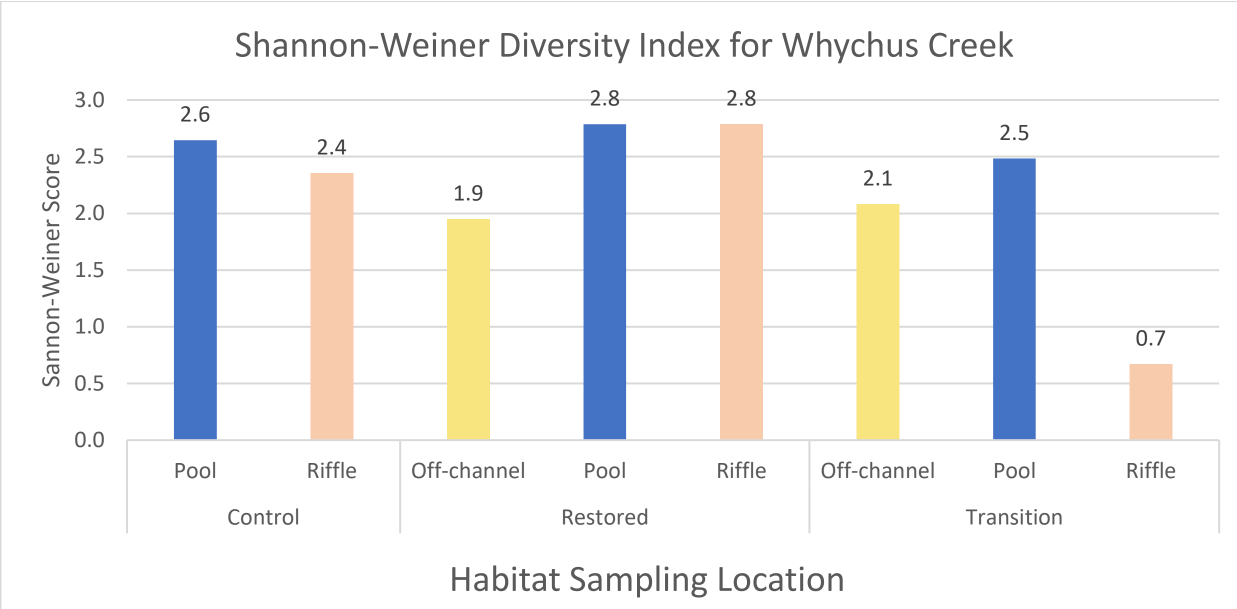

Figure 4: Bar plot showing calculated Shannon-Weiner Diversity Index for the sampled locations at Whychus Creek with data from Noone et al. 2023.

Time since restoration of sampling – From literature	
Mean	5.52 years
Standard Error	1.20 years
Maximum	25 years
Minimum	1.33 years
Count (n)	28 sampling times represented

Table 7: Summary of the times of sampling since restoration in the literature.

Title	Riffle v Pool v off-Channel	Shannon Index	Time since restoration (years)
Assessing macroinvertebrate community response to restoration of Big Spring Run: Expanded analysis of before-after-control-impact sampling designs	ONLY collected within riffle habitats	N/A	5
Connectivity restoration of floodplain lakes: an assessment based on macroinvertebrate communities	not addressed in study	3.8	5
Constructed wetlands increase the taxonomic and functional diversity of a degraded floodplain	not addressed in study	N/A in this context	5, 25, 15 years

Contrasting Responses among Aquatic Organism Groups to Changes in Geomorphic Complexity Along a Gradient of Stream Habitat Restoration: Implications for Restoration Planning and Assessment	ONLY collected within riffle habitats	Reference: 2.59 Control 2.44 Restored: average 2.48	2 years, 10 years, and 2
Effectiveness of a Newly Created Oxbow Lake to Mitigate Habitat Loss and positive Biodiversity in a Regulated Floodplain	not addressed in study	1.15	1.33 years
Effects of habitat restoration on the macroinvertebrate fauna in a foreland along the river waal, the main distributary in the Rhine delta	not addressed in study	N/A	3 years
Effects of process-based floodplain restoration on aquatic macroinvertebrate production and community structure	restored: two samples from riffles, two from runs, one from stagnant pool.	N/A	1-2 years
Effects of urbanization and urban stream restoration on the physical and biological structure of stream ecosystems	sampled various sections, pooled results	N/A	1, 2, 5, 6 years
From isolation to connectivity: the effect of floodplain lake restoration on sediments as habitats for macroinvertebrate communities	not addressed in study	Average: 1.47	5 years

Table 8: Shannon-Weiner Diversity Index summary of comparable indexes reported in the literature.

Shannon-Weiner Diversity Index			Average
Control	Pool	2.65	2.50
	Riffle	2.36	
Restored	Off-channel	1.95	2.51
	Pool	2.79	
	Riffle	2.79	
Transition	Off-channel	2.08	1.75
	Pool	2.48	
	Riffle	0.67	

Table 9: Calculated Shannon-Weiner Diversity Index for macroinvertebrates at each site and habitat type at Whychus Creek.

Discussion

Macroinvertebrates' responses to stream restoration

Based on this literature review, 73% of the metrics recorded showed macroinvertebrates responding positively to restoration projects that included floodplain reconnection in the end design. While there are other compounding factors to consider, such as time since restoration, and the techniques implemented to achieve this end goal, this indicates that floodplain connectivity may be a critical strategy to consider. When the stream channel is reconnected via restoration, there are a number of ways the environment is changed that may be encouraging successful colonization and residence by macroinvertebrates.

The reconnection of a channel can create additional habitat types that macroinvertebrates can use. Not only does the physical reconnection allow for travel and colonization (Gallardo et al., 2012), but as different habitat types are created there are more environmental niches available to be filled (Wallace & Webster, 1996). Restoration attempts to create these habitats by varying the sizes of sediment in the streambed, adding large woody debris (LWD), dredging accumulated silt from specific areas, and carefully excavating side-channels to run along the main channel. Through these alterations, off-channel habitats are formed immediately following restoration and over time through flooding events (Riquier et al., 2017) that allow for access to a variety of habitat types. By changing physical characteristics of the stream such as the slope, the width, and the connections to side and off-channels, macroinvertebrates can access resources such as slower moving pools, cooler temperatures, breeding, and spawning habitat, (King & Torre, 2007)

Another way that restoration can help encourage the colonization of macroinvertebrates is by slowing the streams velocity. The addition of large woody debris not only provides a surface for algae growth but can also slow stream flow by helping to establish jams and islands (Meyer et al., 2016.). The use of excavators to create side-channels and redistributing sediment to create connections to ephemeral pools and backwaters creates a more even and connected floodplain which slows water flow to levels more suitable to macroinvertebrates and amphibians (Meyer et al., 2016). During high flow events the newly connected backwater channels act as buffers to flooding, allowing a place for the water to go while also providing refuge for macroinvertebrates. This can increase the level of the groundwater by allowing for more surface area to be penetrated by flood or rainwater, and more time spent on the ground due to the evening of the surface from filling and sediment redistribution (Bring et al., 2022).

By restoring the ecosystem services of a stream, the primary production can be increased (Wang et al., 2021), which can positively affect macroinvertebrates. Primary productivity refers to how quickly new biomass is created within an ecosystem and is typically fulfilled by plants growing and being consumed by small organisms. Macroinvertebrates serve as an important link between this primary productivity and other larger organisms such as the fish and birds that consume them. Habitat heterogeneity created from restoration can be successful in the increased degradation of leaf litter, an important food source for macroinvertebrates (Frainer et al., 2018). When an area is especially degraded due to development or agricultural use, primary production may be increased in the project area through the planting of new vegetation (Wang et al., 2021), or protection of existing native species.

Outcomes of the Whychus Creek Restoration

The restoration at Whychus Creek is not the first of its kind, nor will it be the last, but valuable information can and should be garnered from its outcomes. Its end result shared some similarities with the literature, but there were also differences. The project restored a slightly longer length of reach than the average seen in the reviewed studies but stills falls within the upper quartile range when compared (Figure 2). Reconnecting the creek helped raise its macroinvertebrates species diversity to levels comparable to those seen in the current literature (Figure 4, Table 8). At each site type, restored, transitional, and control, the highest diversity seen was within the pools. The available literature does not provide enough detail to compare the specific habitat types. Sampling of macroinvertebrates took place at varied times-since-restoration for Whychus Creek, as it was restored in sections, and the restored section had a higher value than the transition section (Table 9), indicating that longer time since restoration may lead to more diversity. Compared to the average outcomes found in the literature, the Whychus Creek restoration serves as confirmation that reconnecting streams to floodplains can help improve the macroinvertebrate populations at a site given enough time.

Knowledge Gaps

The most apparent knowledge gap was in the small sample size of available primary studies that measured a before-and-after response to restoration on macroinvertebrates. This may be due to a variety of reasons, including:

- Lack of awareness from natural resource managers on the importance of gathering pre-restoration data
- Lack of funds for pre-restoration data, and post-restoration monitoring
- Macroinvertebrates are not typical “charismatic species”

Based on a review of over one hundred articles and synthesis of nineteen, the most glaring oversight in river and stream restoration projects is the lack of pre- and post-monitoring data. Many articles had to be rejected for review because they did not have the requisite data to observe trends in the macroinvertebrate communities. A substantial portion of the studies monitored non-biologic parameters such as pH, conductivity, temperature, and flow rate, which are all certainly important and still necessary to track. However, by monitoring the macroinvertebrate communities in the stream the project can have better definitions of "success" to guide decisions. One study of restoration projects in the U.S. conducted via interviews with project managers found that "success" was clearly defined at the outset of projects less than half of the time (Bernhardt et al., 2007). The same study also found that even though initial ecological health was often a reason for starting a project, success was not defined by the final ecological health of the same area. Instead, appearance and public opinion were the factors that interviewees cited as being the measurements of success (Bernhardt et al., 2007).

Restoration of floodplains takes place over decades (Louhi et al., 2011), and studies that are less than 10 years following restoration could be considered short-term. Large disturbance events, such as the removal of a dam, may be detrimental to communities of macroinvertebrates in the weeks and months following the removal (Mahan et al., 2021), but long-term impacts are varied. Some long-term projects such as the Rhone have seen majority measures of success, while others, like those in Finland, have more mixed results (Louhi et al., 2011). More than half of the studies represented in this review took sampled macroinvertebrates less than four years following restoration, with only two being studied after twenty years. Because there are still so many unknowns about the long-term effectiveness of many management strategies, continued data collection is needed to assess the emerging patterns. In order to fully understand the effects of actions taken and effectively measure success, management should invest resources into extensive pre- and post-monitoring data collection.

Recommendations

It would be economically infeasible and likely impossible to measure all the metrics of response that a river ecosystem will experience in response to restoration. Sampling for and recording macroinvertebrates, however, is one such metric that may prove invaluable to study. They can act as indicators of water quality, as certain species and taxa are more sensitive than others and gathering them does not require expensive tools. Studies can be done using the help of volunteers and student-scientists to collect data, and data analysis can be simplified to save time and money (Edwards, et al. 2020)

In educational settings, macroinvertebrates are relatively easily seen with the naked eye, and therefore can act as a pseudo-charismatic species to some. Education about macroinvertebrates can start with elementary children and help cultivate a better understanding and appreciation for the natural environment that isn't always as plain to see. If more people are exposed to the benefits of studying macroinvertebrates and how they play vital roles in our streams, they may care more about them, and that in turn could translate to more funding further in the future, as we've seen with species such as the bald eagle, and grey wolves.

With the proper training and oversight, monitoring of macroinvertebrates before, during, and after stream restoration can provide valuable, measurable biological data to scientists and environmental managers, enabling them to make more informed decisions. Having information on which communities of macroinvertebrates are present allows diversity indices such Shannon-Weiner to be calculated, and enables comparison to other restored, or pristine ecosystems, and can help managers track the progress of their efforts.

Whychus Creek saw similar Shannon diversity indices as compared to the literature of other restored floodplains, which overall saw macroinvertebrates having a mostly positive response to this style of restoration. However, due to the relatively shorter amount of time since restoration, one recommendation is to continue to perform yearly monitoring of the macroinvertebrates at the site. The literature review revealed that most studies do not perform monitoring after ten years, which creates a knowledge gap. Based on the fact that 73% of the studied macroinvertebrate indices saw a positive response to increasing floodplain connectivity, other recommendations are that restoration projects aim to increase the lateral hydrological connectivity of streams in floodplains, in order to capitalize on the range of benefits that increased connectivity of waterways provides. Macroinvertebrates, salmon, and people alike, all stand to benefit from better connected streams.

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