A Spatial Analysis of the Impact of Low-Head Impoundments on Macroinvertebrate Communities

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Abstract. Impoundments block the flow of water and sediments and thereby affect water quality and macroinvertebrate communities. Most environmental concern focuses on the effects of large-scale dams and their range of impacts. I examined both upstream and downstream macroinvertebrate communities of low-head impoundments and to determine the spatial range of their effects. Sampling was conducted upon six different dams along the East Fork of Indiana's White River throughout July of 2018. Water quality variables were measured, and the invertebrate community sampled at seven upstream and seven downstream locations at each dam. Results suggest that there were differences between upstream and downstream communities with the potential to determine spatial differences. The results have implications for river conservation.

Introduction

Dams have a long history in the United States and were associated with most pre-nineteenth century cities in close proximity to rivers. Dams served to harness power from rivers and provided a source of free energy which could be used to turn grinding stones procuring flour or powering textile mills. These dams are classified as low-head impoundments (< 3 meter height) as they are smaller, their function is to raise the water head just enough to generate the necessary power to turn a wheel and, power machinery.

However, during the industrial revolution dams were abandoned in favor of steam or electrical power. These abandoned dams were made from concrete or stone and so are durable and can have a lifespan of >100 years (Vinson 2001). Currently in the United States there are around two million dams, 96% of which are low-head dams and under 2 meters in height (Tiemann and Gillette 2004).

Impoundments on rivers reduces the total area of free flowing water and increases the area of impounded waters. Impounded waters cause river fragmentation which reduces river system connectivity and prevents the movement of migrating fish. Dams alter stream physiology which causes negative biotic effects both upstream and downstream of a dam (Santucci 2005; Tiemann and Gillette 2004; Thomson et al. 2005; Lin 2011). Before the placement of a dam, rivers are characterized as lotic however; impounded waters are altered to lentic. This is accompanied with an altering of streamflow; upstream waters have a much lower velocity while downstream reaches are subjected to high velocities (Thomson et al 2005; Tiemann and Gillette 2004). In addition, impoundments can cause siltation upstream if waters are turbid and downstream scouring can be common and exacerbated by flooding. This shift in environment is more pronounced in large dams, but still occurs on a smaller scale with low-head dams. Rivers are normally characterized by gradual changes in their course downstream. This abrupt juxtaposition of environments has the potential to lend itself to interesting interactions.

This study focused on the East Fork of the White River watershed of Southern Indiana which drains 5,725 mi^2 before the confluence with the West Fork of the White River (Hoffman 2003)(figure 1). Six low-head dams were selected as study sites, due to their similar sizes and spread throughout the same watershed.

Figure 1. The White River Watershed. The focus of the study was upon the middle east fork.

Methods

At each of the 6 impoundments selected for study on the East Fork of the White River (Figure 1), 14 Hester - Dendy traps were used to sample the macroinvertebrate communities (7 upstream and 7 downstream). Hester - Dendys were selected over other methods due to dangers associated with sampling in close proximity to dams. In addition, environmental conditions above and below dams vary significantly so a uniform method of collection was required. Traps were placed 10, 20, 40, 60, 90, 120, and 170 feet from the dam both upstream and downstream.

Traps were placed in early June and colonized for one month. Traps were disassembled and plates washed, samples were then stored in 75% ethanol. Specimens were later identified to major taxa.

Water quality was measured with a Multiparameter Data Sonde at the same interval as the traps. Measures were taken of dissolved oxygen (DO), Water Pressure, Temperature, conductivity, pH, and Oxidation reduction potential (ORP)

Results

Water Quality. Water quality measures were plotted to observe changes while passing over the dam. The greatest change occurred with the variables dissolved oxygen (DO) and oxidation reduction potential (ORP). (Figure 2A-B) The ORP rises until over the dam where it gradually returns to pre-dam conditions. This is the only water quality variable in which full recovery to pre-dam conditions was observed. The DO means steadily climbs until reaching the dam where it drops right before crossing over the dam, then reaching a climax and maintaining levels higher then the upstream for the rest of the study area.

There are relatively no changes in pressure and temperature. The Conductivity and pH data suggests that there could be trends; however, there was a lack in significances in our data.

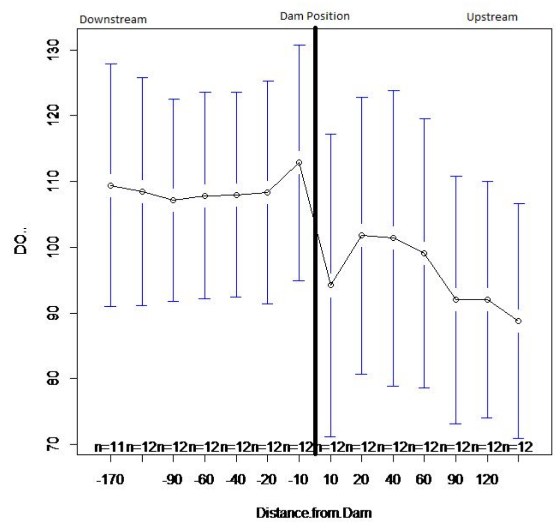

Figure 2A. Mean plot of Dissolved oxygen levels upstream and downstream of impoundment

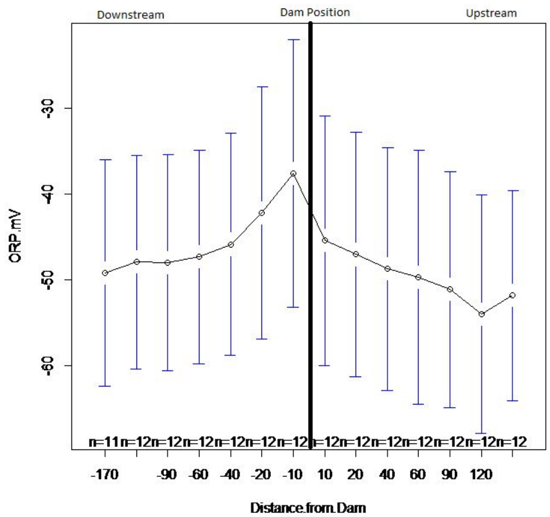

Figure 2B. The change in oxidation reduction potential (ORP) of upstream and downstream of impoundment

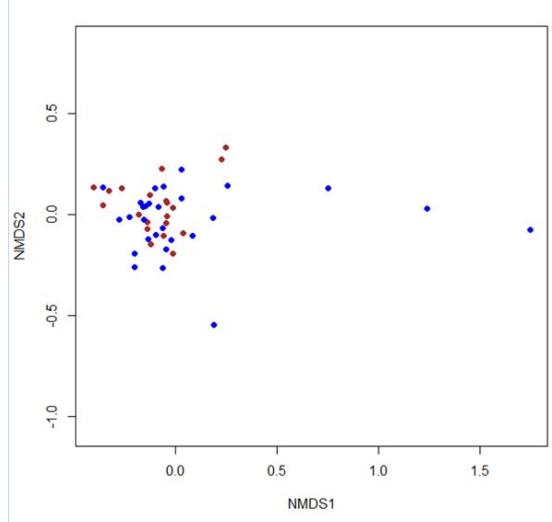

Figure 3. Non-Metric Multidimensional Scaling (NMDS). The Blue dots are upstream sites and the red are downstream.

Macroinvertebrate Communities. The upstream and downstream communities were compared through a NMDS and I determined that the macroinvertebrate community compositions of major taxa were similar (Figure 3). Although the compositions were similar we found trends examining taxa present, (Figure 4). The downstream was very uniform in the number of taxa; in contrast, the upstream was highly variable with numbers both above and below the downstream. The downstream contains more total individual variability while the upstream is very uniform, excluding the first site at 10 ft.. This trend is observable in examining Ephemeroptera and Trichoptera densities in which uniform populations are shown upstream, but are varied downstream, (Figures 6 & 7).

Synthesis. To examine the relationships between the macroinvertebrates and water quality, a redundancy analysis (RDA) was conducted, (see figure 8). The RDA showed several trends; as the oxygen content in the water went up so did the Ephemeroptera populations and the distance from the dam increased there was a higher quantity of Gastropoda, Coleoptera, and Zygoptera. There was also a trend between temperature increases and Trichoptera populations.

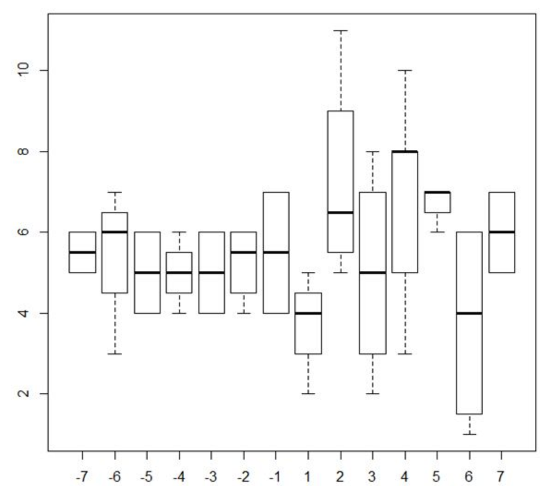

Figure 4. Total richness of sites the upstream is more variable and the downstream is uniform. Downstream is depicted as negative while upstream is positive

Discussion

The increased levels of oxygen in the downstream portions of dams should create better habitats for the macroinvertebrate communities; however, that is not shown in the data. During the one-month study period there were two large flood events, (Figure 9). Dams provide shelter upstream, but cause a severe increase in velocity downstream causing scouring of the river bed. This leads to many insects getting washed downstream unless they are in protected conditions (Tiemann and Gillette 2004).

In determining the spatial distance of the impact of a dam, it was determined the effects will extend beyond the 170 feet examined in this study. What is unknown is if the water quality recovers at a distance beyond what was measured or if there is no recovery. This is supported by the DO means plot, which demonstrates that the change in DO is present but does not return to pre-dam conditions. In the macroinvertebrate data, the upper and lower limits never reach an equilibrium suggesting the need to examine greater distances.

The spatial range could potentially be determined by expanding the range of sampling both upstream as well as downstream of the dam. Doing so would allow for a better understanding of the water quality as well as the biotic communities.

The biologic data could be improved upon by increasing the overall dam sample size to eliminate the standard error and determining better methods to prevent the loss of traps. The data could also reveal more information if examined at lower taxonomic levels.

The water quality data could be improved by examining variables which could fill in the gaps such as turbidity and velocity. By including these variables, it could be possible to determine the effects of the increased velocity.

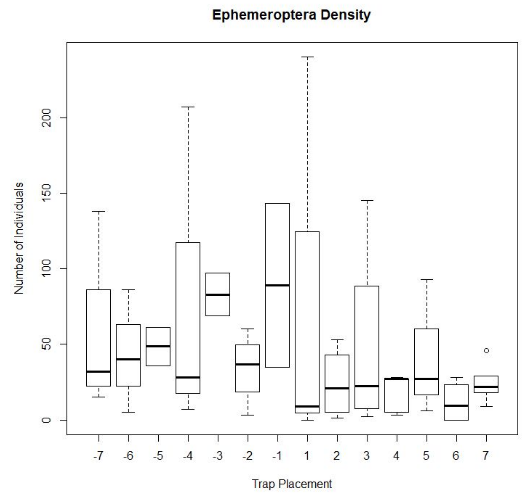

Figure 6. Ephemeroptera Density. Downstream is negative while upstream is positive

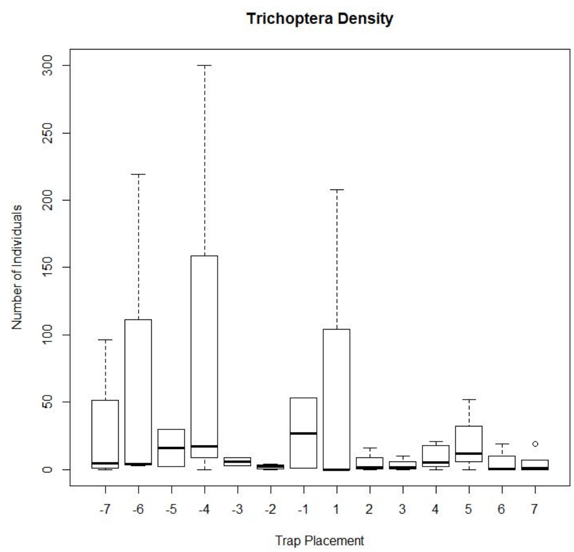

Figure 7 Trichoptera density. Downstream is negative while upstream is positive.

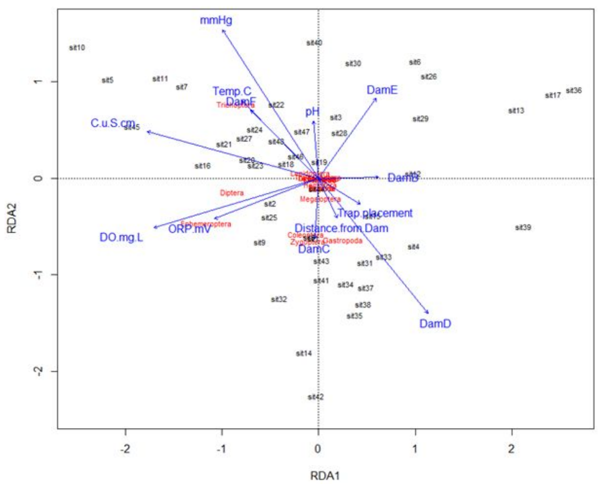

Figure 8. Redundancy analysis. Red is biotic data and blue is water variables.

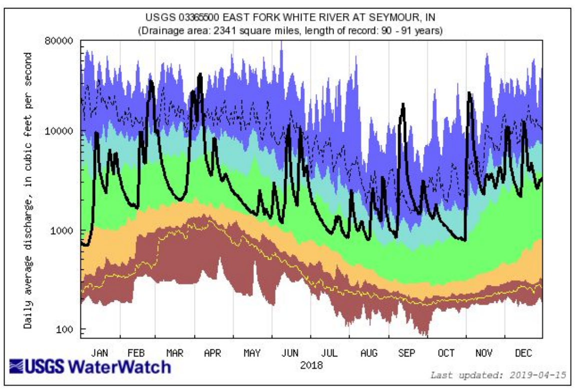

Figure 9. Hydrograph of East Fork of the White River during 2018. During study duration (June) flood events are observable.

Conclusions

Currently, there are debates surrounding the removal of dams, particularly in areas of migrating fish, such as the Western United States' Salmon. Removing dams is costly and risky, so the more understanding that can be added to existing knowledge will lead to informed decision making.

Low-head impoundments have a contrasting anthropogenic effect upon macroinvertebrate communities in the East fork of the White River. The water quality downstream of a dam is improved by oxygenation while passing over the dam, but the biotic data shows variability which could be explained through higher flow velocities downstream and increased velocity during flood conditions. The spatial analysis results suggests that river systems either do not recover or that they recover beyond distances measured.

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