The downstream effects of dam removal on the distribution of nutrients and sediments

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EEB 381 – General Ecology
8/17/2015
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Abstract

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Introduction

Over the last century, America has led the world in dam building, reconstructing and harnessing rivers for hydropower, irrigation, flood control, water storage, and other purposes (Bowman, 2002). Now, over 87,000 dams spread along the waterways of our nation, including at least ten thousand smaller dams scattered throughout our rivers and streams (USACE, 2013). Despite the many benefits provided by dams, some are no longer capable of efficient use and have significantly affected the productivity of our environment. Aging dam infrastructures often contribute to biodiversity loss, spreading of invasive species, and a high maintenance cost, in which, dam removal is spotlighted as an important restoration opportunity.

While there are many essential ecological benefits to dam removal, such as reconnecting fish migration routes (Schmetterling, 2003), it is undetermined if these benefits outweigh the possible damages brought to downstream communities, including substantial nutrient exports, sediment releases from reservoirs or flash floods, and disruption of existing communities (Gray and Ward, 1982; Doyle et al., 2002; Burdick and Hightower, 2006). Unfortunately, decisions about dam removal have been made complex due to the lack of pre- and post-removal studies and uncertainty over potential environmental benefits (Hart et al., 2002). Most concerns about the downstream effects of dam removal focuses on the remobilizing of sediments and nutrients from the former impoundment (Stanley and Doyle, 2002). Much of which accumulated over the past few years, and could cause subsequent changes in substrate and nutrient concentrations downstream (Stanley and Doyle, 2003).

In this study we analyze the potential affects a dam removal can have on erosion and chemical composition of a preexisting body of water. Majority of nutrients before removal are stored in lake's benthos (Perrin et al., 2000; Stanley and Doyle, 2003). With the dam removed, the upstream sediment becomes exposed and complex biogeochemical reactions begin. Sediments become oxidized, mobilizing metals to bind with certain species (de Carvalho et al., 1998) and confine phosphate (Kleeberg and Heidenreich, 2004). Nitrogen in the sediment may then be mineralized, nitrified (Sparling and Ross, 1988), leached (Perrin et al., 2000), or denitrified (Kern et al., 1996). Thus, the reason predicting the environmental cost from dam removal to be complex.

The recovery from disturbances may take several years, however, not all sediment inputs lead to a decline in aquatic productivity. A Colorado State University study found that sediments released from a reservoir resulted in downstream algal growth, due to an increase in phosphorus (Gray and Ward, 1982), but others have also found no direct effect between sediment deposition and algae (Schofield et al., 2004). In agricultural watersheds, fertilizer usage often leads to phosphorus-rich sediment being transported to aquatic ecosystems (Bennett et al., 2001). The phosphorus is trapped and stored for years in the sediment until released during events such as dam removal (Stanley and Doyle, 2002).

Our study measured and collected substrate levels, sediment compositions, and varied environmental components in both bodies of water to be later referenced in future studies about the affects dam removal have on aquatic ecosystems.

Materials and methods

Study sites and sediment collection

We collected sediment and gathered environmental data of 20 sites above and below the Lake Kathleen Dam in Tranverse City, MI. We focused on the two most potential locations to be affected by dam removal, Lake Kathleen (10 sites) and the Maple River Combined Branch (5 sites), in which, 2 canoes were used for travel and transport.

Lake Kathleen sites were randomly selected, with the inclusion of 2 sites in both the East and West Branch by using a Garmin GPS 60 to determine GPS coordinates of each site. An Eckman dredge was used to collect sediment at the lake's bottom and each sample was deposited into a gallon plastic container. The containers were then labeled and placed in an iced cooler for storage.

Maple River Combined Branch sites were predetermined based on previous analyses and most dominant microhabitats. Due to a change in sediment deposition across river channels, sites were sectioned into cells using a 1 m^2 PVC square in wide channels and a 1/2 m^2 PVC square in narrow channels. Using a steel gardening spade, 2 cm of sediment was collected from each cell of a site and were deposited into separate 1 gallon plastic containers if a difference is grain size (clay, sand, cobble, etc.) was noticed. The containers were then labeled and placed in an iced cooler for storage.

Temperature (°C) and dissolved oxygen levels (mg/l) was also monitored at each site using a DO (Dissolved Oxygen) meter. The DO meter was placed a 1/2 m within the water of each site and data of temperature and dissolved oxygen levels were recorded. We analyzed temperature and dissolved oxygen levels because it represents the current conditions under which sediments were collected. These variables could be potentially changed after dam removal, affecting sediment and chemical composition of the water.

Sample Analysis

Each site container was mostly drained of water and placed in 3 separate 50 ml acid-washed centrifuge tubes and a 500 ml Nalgene wide mouth bottle. The dry weight and chemical composition of each sample was then analyzed using the following methods:

- **Dry weight:** 10 g of wet sediment from the Nalgene bottle was weighed on a metal tin and dried at 60 °C for 48 hrs. The sample was reweighed after drying.
- **Nitrate (NO_3) and Ammonia (NH_4):** 2 g of wet sediment from a one centrifuge tube was placed into a 40 ml solution of 2 M KCl. The mixture was shaken for 60 min in a tube shaker, filtered, and given to chemist Tim Veverica for a chemical analysis.
- **Phosphate (PO_4):** 0.2 g of sediment from another centrifuge tube was placed into Troug’s solution, shaken for 60 min in a tube shaker, and given to chemist Tim Veverica for a chemical analysis.
- **Carbon (C) and Nitrogen (N):** The sediment from the final centrifuge tube was placed on a metal tin and dried at 100 °C for 48 hrs. The dried sediment was milled and given to chemist Tim Veverica for a chemical analysis.

Sediments were classified using the Wentworth Scale, with fine sediments shifted through a series of varied sieves and cobble sediments measured using digital calipers. Sizes were recorded on a table.

Analysis of collection and composition data

Using IBM SPSS statistics software, we created 6 individual t-tests, one for each tested nutrient, to analyze if there was a significant relationship between average nutrient levels (dependent variable) and site location (independent variable) under a 95% confidence interval. Finally, we designed a regression analysis to assess whether or not there was a significant relationship between the distance downstream and particle size.

Results

Substrates

We detected no significant difference for average NO_3, NH_4, and C:N ratio levels between Lake Kathleen and the Maple River Combined Branch. Although, a significant relationship was found for average PO_4, C, and N levels between both environments. After a chemical analysis, it was determined that Lake Kathleen contains 108.28 ug/L (± 121.98) of $NO_{3,}$ 293.82 ug/L (±79.7) of $NH_{4,}$ 126.45 ug/L (±14.26) of $PO_{4,}$ 21.19% (± 4.71) of $C_,$ 1.53% (±0.38) of $N_,$ and an C:N ratio of 16.04 M (±1.24) (Fig. 1). While, the Maple River Combined Branch contains 44.98 ug/L (±37.80) of $NO_{3,}$ 206.86 ug/L (±54.34) of $NH_{4,}$ 55.42 ug/L (±12.75) of PO_4, 0.25% (± 0.11) of $C_,$ 0.01% (±0.01) of $N_,$ and an C:N ratio of 14.6 M (±12.28) (Fig. 1). The 95% confidence interval of the two sites overlap between NO_3, NH_4, and C:N ratio levels, deducing, that there is no conclusion. However, PO_4, C, and N levels at Lake Kathleen are significantly greater than levels at the Maple River Combined Branch (Figure 1). Six independent T-tests between nutrient levels revealed that there was no significant difference in

NO_3 ($t = 0.7$, $df = 13$, $p = 0.5$), NH_4 ($t = 1.41$, $df = 13$, $p = 0.18$), and C:N ($t = 0.23$, $df = 4.08$, $p = 0.83$), but a significant difference in PO_4 ($t = 6.24$, $df = 13$, $p < 0.001$), C ($t = 6.05$, $df = 13$, $p < 0.001$), and N ($t = 5.45$, $df = 13$, $p < 0.001$).

Sediments and soil

We detected a relationship between the weight of sediment size distributions (g) in both Lake Kathleen and the Maple River Combined Branch. The percentage of sediment distributions ranged from silt/clay - cobbles with Lake Kathleen being comprised of mostly medium - fine sand at 545.7 g (81.48%), and Maple River Combined Branch comprised of mostly pebbles - cobbles at 4743.27 g (71.22%) (Fig. 2). As a result of this distribution, in which the pebble - cobble make-up of the Maple River is consisted primarily of medium – fine pebbles (), water content of the soil in Lake Kathleen is particularly higher than those at the Maple River (). Chi squares revealed that there was a significant difference between sediment distributions within Lake Kathleen ($X^2 = 1589.9$, $p < 0.001$) and Maple River ($X^2 = 15123.6$, $p < 0.001$), thus, rejecting that there is an equal distribution of sediments within both environments. A T-test shows that there is a significant difference between water content in the soil of both locations ($t = 8.7$, $df = 13$, $p < 0.001$).

Discussion

The present study tested the notion that differences in sediment composition are seen within Lake Kathleen and the Maple River Combined Branch, and that substrate/sediment distributions and aquatic biota downstream are affected by removal of the Lake Kathleen Dam. We hypothesized that the still water of Lake Kathleen would harbor more fine sediment, while the rapid motions of the Maple River Combined Branch would be composed of mainly larger sediment particles. Due to this build-up of fine sediments and organic material at the bottom of Lake Kathleen, the substrate of the Maple River Combined Branch would change following dam removal and, in turn, affect many aquatic ecosystem factors. Since the Lake Kathleen Dam is still intact, our results give the current conditions of Lake Kathleen and the Maple River Combined Branch prior to dam removal.

After analyzing our results, we first concluded that there was relationship with PO4, C, and N levels, however, not with NO_3, NH4, and C:N ratio levels between both locations. This could be attributed to PO4 and N being the most common nutrients found in fertilizers and nutrients from nearby farmland could leech into the lake from groundwater (Fluxes of particulate carbon, nitrogen, and phosphorus) in the upper water column of the northeast Pacific. The still water of the lake would allow for the nutrients to accumulate over time, causing an increase in levels of PO_4 and N. Thus, algae and aquatic plant productivity could be seen higher in this area, increasing C levels from the CO2 made by their respiration. Low levels of N and other nutrients in the Maple River Combined branch could also be attributed to sites on the river having N levels below detectable limits and not have enough time to sample more sites, which can lead to potentially unreliable statistical data.

We then recognized that there was a significant difference between sediment distributions within the lake and river. Lake Kathleen samples were composed of more fine sediment than the large coarse sediment of the Maple River Combined Branch. The outcome could have been a result of the fast moving current from the river causing larger particles to move downstream while more eroded sediment deposits in the lake (Erosion, transport and deposition of fine-grained marine sediments). Also, collected lake sediments formed hard blocks after drying and had to be milled into small particles to be prepared for chemical analyses.

After dam removal, the high levels of nutrients and sediment composition of Lake Kathleen will be deposited downstream affecting many ecosystem parameters of the Maple River such as macroinvertebrate communities, fish communities, algal and aquatic plant productivity, and riverbed formations. Some of which will take longer than others to recover (Doyle et al., 2005). However, the high levels of PO4, C, and N trapped in the lake's sediment will have a greater effect on the river ecosystem. Sediment in Lake Kathleen is considered allochthonous to the Maple River Combined Branch since the dam currently prevents it from being transported downstream. Once the dam is removed, the allochthonous carbon and nutrients could potentially lead to eutrophication and cause algal blooms. The large abundance of algae will then block sunlight from aquatic plants, thus, limiting the primary productivity that causes their deaths. Soon, bacteria will use all concentrated oxygen within the water to decompose algae, killing all living aquatic organisms ().

Also, the redistribution of sediment after dam removal will greatly affect macroinvertebrate communities. The higher inputs of fine sediment from Lake Kathleen could disturb the diverse macroinvertebrate communities that thrive on larger coarse sediments of the Maple River Combined Branch, hindering the growth of macroinvertebrates and various aquatic plants. If aquatic plants are decimated, algae can take over and flourish. The potential for flourishing algal bloom populations could lead to anoxic aquatic environments unsuitable for fish life. Especially since fish populations take up to decades to recover after dam removal (Doyle et al., 2005) the potential for an anoxic environment could be extremely dangerous to the river ecosystem.

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