Original Research Paper

Conductivity increased in Upper Ohio River Valley streams during the hot and dry summer of 2020

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Abstract: As the climate changes, extreme weather is becoming more common. Of particular concern for aquatic ecosystems are prolonged droughts and extreme heat waves. Droughts can lead to low flow conditions and increased concentrations of dissolved salts in stream water, which can stress aquatic organisms. The summer of 2020 was exceptionally hot and dry in the Upper Ohio River Valley and we analyzed water chemistry data collected from 24 sites from the summer months of 2019 and 2020 to determine if there were any significant differences between water temperature and specific conductance (SPC) between the two years. Sampled streams ranged in size from headwater streams to 8th order rivers and impairment ranged from biologically healthy to severely impacted by acid mine drainage (AMD). We found conductivity to be significantly higher at 14 of the 24 sites in 2020, but water temperature was significantly higher in only one of the 24 sites. In our non-AMD impacted sites, conductivity increased by 88 $\mu S\ cm^{-1}$ on average (range = 28 – 303) in 2020, while conductivity at AMD impacted sites increased between 166 – 1,502 $\mu S\ cm^{-1}$. Rising temperature and increasing conductivity create challenges for sensitive species while more tolerant species become more dominant.

Keywords: conductivity; water temperature; low flow; streams; summer; climate change

Introduction

Climate change is altering freshwater ecosystem structure and function through increasing water temperature (Rutherford, et al., 2004), and increasing frequency, duration and severity of droughts (Humphries & Baldwin, 2003). Increasing water temperature can influence fish physiology (Mohseni, et al., 2003), macroinvertebrate community structure (Grimm, et al., 2013; Marziali & Rossaro, 2013), and biogeochemical cycles (Jabiol, et al., 2020; Arismendi, et al., 2012; Duan & Kaushal, 2013). Warmer streams and rivers are also expected to have increased carbon emission due to increased heterotrophic activity (Song, et al., 2018), influencing organic matter processing rates (Ferreira & Canhoto, 2014) which in turn impacts trophic relationships. Furthermore, elevated water temperatures can also increase evaporations rates, exacerbating low flow conditions and further impacting freshwater ecosystems.

Climate change is also prolonging drought conditions in many regions of the world (Smakhtin, 2001; IPCC, 2021). The effects of drought may be most pronounced in watersheds with reduced forest cover which can reduce inflitration and recharge (Price, et al., 2011). Reduced recharge of groundwater can result in more pronounced low flow conditions during drought. Drought may also facilitate changes in water chemistry by increasing the reliance on groundwater which can have stored salts and metals from adjacent land use such as runoff from roads and parking lots where deicing salts are frequently used (Cooper, et al., 2014). Additionally, streams in watersheds impacted by urbanization, agriculture, and mining commonly have higher conductivity (Walsh, et al., 2005; Pond, et al., 2014). Conductivity, a measure of the dissolved salts, metals, and ions in the water, and elevated conductivity can stress aquatic biota (EPA, 2016; Pond, et al., 2014; Walsh, et al., 2005). Thus extreme weather events caused by climate change may amplify the effects of low base flow, general warming, and conductivity on stream organisms.

In the Upper Ohio River Valley, 2020 was notably drier than average and was one of the hottest years on record, 2020 tying 2016 as being one of the hottest years on record since 1880 when record keeping begun (NASA/GISS, n.d.). In the summer of 2019 precipitation was on par with the typical average for the Wheeling, WV area but the summer of 2020 precipitation was below the average. In 2020 precipitation was 2x lower than the average as well as being 2x lower than what accumulated in 2019 (National Weather Service, 2021). Streams in the area are typically low in later summer with the minimum discharing in 2019 reaching 15 cfs but in 2020 the minimum discharge was close to ½ of what was obserbvered in 2019 reaching approximately 8 cfs in late August and September (USGS, 2021). The combination of high air temperature and low precipitation in the summer and early fall resulted in low flow conditions in tributaries to the Ohio River near Wheeling, WV. To better understand the effects of the hot dry summer of 2020 on streams in the Upper Ohio River Valley we asked the following questions: 1) Was water temperature elevated in 2020 compared to 2019? and 2) Was conductivity elevated in 2020 compared to 2019?

Materials and Methods

We selected 24 sites in the Upper Ohio River watershed near Wheeling, WV (Fig. 1), where we routinely collected weekly or biweekly water chemistry data as part of a long-term monitoring program. We defined "summer" as ranging from June 1st to September 30th as indicated by light blue (2019) and red (2020) bars on the USGS hydrograph (Fig. 2). Sites were sampled between 8 and 18 times during the summer of 2019 and between 12 and 16 times during the summer of 2020. Sites included headwater streams, mid-order rivers, and the Ohio River (an 8th order stream). Some sites were in good biological condition and others were impacted by acid mine drainage (AMD), urbanization and other land uses. Water temperature and specific conductivity (SPC) were measured in the field with a calibrated YSI QuatroPro field meter. Wilcoxon Signed Rank test (similar to a T-test) was used to determine if water temperature and conductivity were significantly different between summer 2019 and summer 2020, values were unweighted by sampling frequency or discharge. We then assessed correlations between watershed size, water temperature, and conductivity, and the change in temperature and conductivity between 2019 and 2020.

Figure 1. Black star indicates the approximate sampling locations of 24 sites in 3 primary watersheds that drain into the Ohio River plus 2 direct tributaries to the Ohio River. Primary drainages include the Ohio River, Wheeling Creek, Short Creek, and Buffalo Creek, direct tributaries include Glenn's Run and Caldwell Creek.

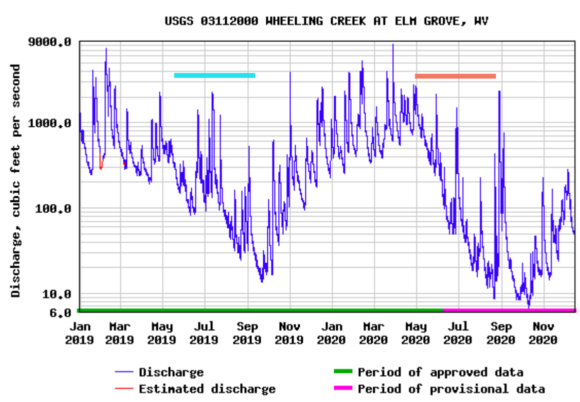

Figure 2. Hydrograph of Wheeling Creek near Wheeling, West Virginia from January 2019 to December 2020. Light blue bars indicate summer 2019, and red bars indicate summer 2020. Note the lower discharge in the summer and early fall of 2020 compared to 2019.

Results

Across all 24 of our study sites, mean summer water temperature in 2020 was higher than in 2019 in 47% of the sites, but only one of the sites was significantly warmer, and one site was significantly cooler (Table 1, Fig. 3). We found that summer mean conductivity was numerically higher in all 24 sites in 2020 compared to 2019, but only significantly higher in 14 of the 24 sites (58%). Across all sites watershed area was only not significantly correlated with conductivity in 2019 (R^2= 0.06, p-value = 0.26) or 2020 (R^2 = 0.04, p-value = 0.36) however, watershed area was positively correlated with water temperature in both years (2019, R^2 = 0.34, p-value = 0.003; 2020, R^2 = 0.50, p-value = 0.0001). The mean difference in water temperature between 2019 and 2020 was weakly correlated with watershed area (R^2 = 0.16, p-value = 0.6); while conductivity was not significantly correlated (R^2 = 0.20, R^2 = 0.01, P > 0.05).

Averaged across our 21 sites not impacted by acid mine drainage (AMD), mean conductivity was higher in 11 of the 21 sites (52%). Conductivity increased by an average of 88 µS cm^{-1} (range 21.9 – 302.9 µS cm^{-}1) while water temperature increased by 0.2ºC (range -1.4 – 1.7 ºC) in summer of 2020 compared to 2019. With AMD sites removed, watershed size and temperature were modestly correlated in 2019 (R^2 = 0.39, p-value = 0.004) while in 2020 correlations were stronger (R^2 = 0.60, p-value = 0.00003). Conversely, correlations with watershed area and conductivity remained non-significant (2019, R^2 = 0.13, p-value = 0.1; 2002 R^2 = 0.08, p-value = 0.22).

Of the three AMD impacted sites, none had significantly higher mean summer temperature in 2020, while one site was significantly colder. However, conductivity at two of the three AMD impacted sites was significantly higher in 2020, while the third site had marginally higher conductivity. On average conductivity increased by 773 µS cm^{-1} at the AMD sites (range 165-1502 µS cm^{-}1) but mean water temperature decreased by 1ºC in 2020 (range -0.3 – -1.4ºC).

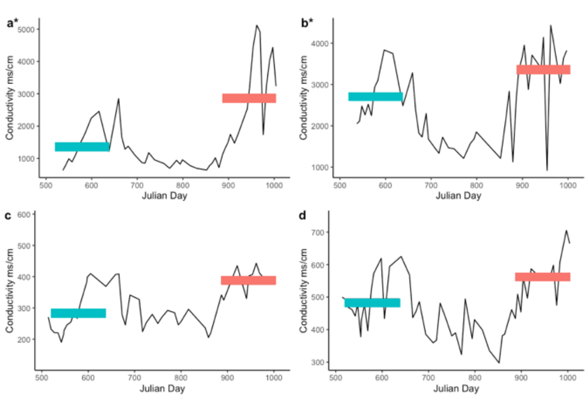

Figure 3. Conductivity (SPC) of four of the 24 water quality monitoring sites between summer 2019 and 2020; ChCr01* (a), NrCr*(b), OhRv01 (c), and WeCr07 (d). Blue bars represent the summer period and the mean SPC for 2019 while red bars represent the summer period and mean SPC for 2020. Summer was defined as from June 1st to September 30th. An "*" indicates a site is impacted by acid mine drainage. Julian Day 500 is May 15th, 2019 of a water quality monitoring data set. Conductivity was significantly different (P<0.05) in summer 2019 than summer 2020 in all sites shown.

Discussion

Our data suggests that hot and dry conditions in 2020 increased conductivity of stream water in the region compared to 2019, which supports other studies reporting increases in stream water salinity in similar weather conditions (Kaushal, et al., 2019). At our non-AMD sites, we found that conductivity was on average approximately 88 µS cm^{-1} higher in 2020 compared to 2019. In pristine Appalachian streams conductivity generally ranges from 100-150 µS cm^{-1} while in anthropogenically impacted streams conductivity can rise well over 1,000 µS cm^{-1} (Hitt, et al., 2016). In 2020 conductivity at all of our AMD impacted sites was over 1,000 µS cm^{-1}, with the highest conductivity reaching over 3,000 µS cm^{-1}. The observed changes at AMD sites may be the result of a decrease in shallow surface influent derived from recent precipitation events, resulting in reduced dilution of high conductivity stream water coming from mines. Furthermore, when groundwater fed AMD impacted sites discharge into larger streams experience low flow conditions, the impact of the AMD stream may be amplified, and the effects of increased conductivity may be extended further downstream

Watershed area explained between approximately 40-60% of the variation in water temperature in 2019 and 2020. Even though mean temperature was higher in 47% of sites, the difference was not significant. The lack of significant difference in temperature between 2019 and 2020 may have been influenced by an increased reliance on cool ground water or a series of intense but short duration rainstorms that rapidly increased discharge in Wheeling Creek from less than 10 cfs to over 1000 cfs, after which discharge fell to approximately 6 cfs. Long term increases in water temperature are anticipated due to the effects of climate change which will affect local biodiversity (Luce, et al., 2014). The effects of extreme weather events, which are predicted to increase in frequencey with climate change (IPCC, 2021) may have more immediate effects on local biodiversity, and the effects may be most pronounced in streams in regions impacts by AMD and other water quality impairments. The combined effects of increasing temperature and conductivity are likely to faciliatate changes in local community composition, shifting communities to become dominated by pollution and warm water tolerant species.

Chronic exposure to high conductivity has been correlated with the decrease in sensitive fish species populations (Hitt, et al., 2016). Morgan II et al. (2012) observed that when conductivity is between 230 and 540 µS/cm it degrades fish communities present, Zhang et al. (2019) found that when conductivity exceeds 500 µS/cm fish abundance begins to decline, while Pond et al. (2014) has reported a 300 µS/cm threshold for conductivity before impacts to macroinvertebrate communities are widely observed. In our streams, only 8% of the samples taken were below the 300 µS/cm threshold for macroinvertebrate communities in 2019 while during 2020 no samples were below the threshold, raising concerns about preserving stream biodiversity in a drought prone future climate scenario. During 2019, 54% of the samples taken were below the 500 µS/cm threshold for fish species while in 2020 only 34% of samples were below that threshold, illustrating how drought induced low flow events alone can cause chemical changes to water quality that negatively impact stream biota.

Protecting and restoring biodiversity in freshwater streams in the Upper Ohio Valley will likely become more challenging with increased pressures from climate change and increased frequency of extreme weather events because of the interacting stresses of increased conductivity and elevated water temperature. Conservation actions that preserve riparian shading may mitigate high temperatures by increasing stream shading (Beschta, 1997; Rutherford, et al., 2004). Similarly, riparian buffers may mitigate some of the effects of increased conductivity in groundwater by filtering pollutants, either by root uptake or through reduced salt laden run-off. Decreased run-off leads to greater infiltration of precipitation which then recharges of the groundwater and dilutes salts and metals that have accumulated there (Cooper, et al., 2014). In conclusion, this study found conductivty increased during the hot and dry summer of 2020 compared to the more typically wet 2019 summer, which poses additional challenges for the conservtion of stream biota and protection of water quality in an increasingly hot and drought prone future.

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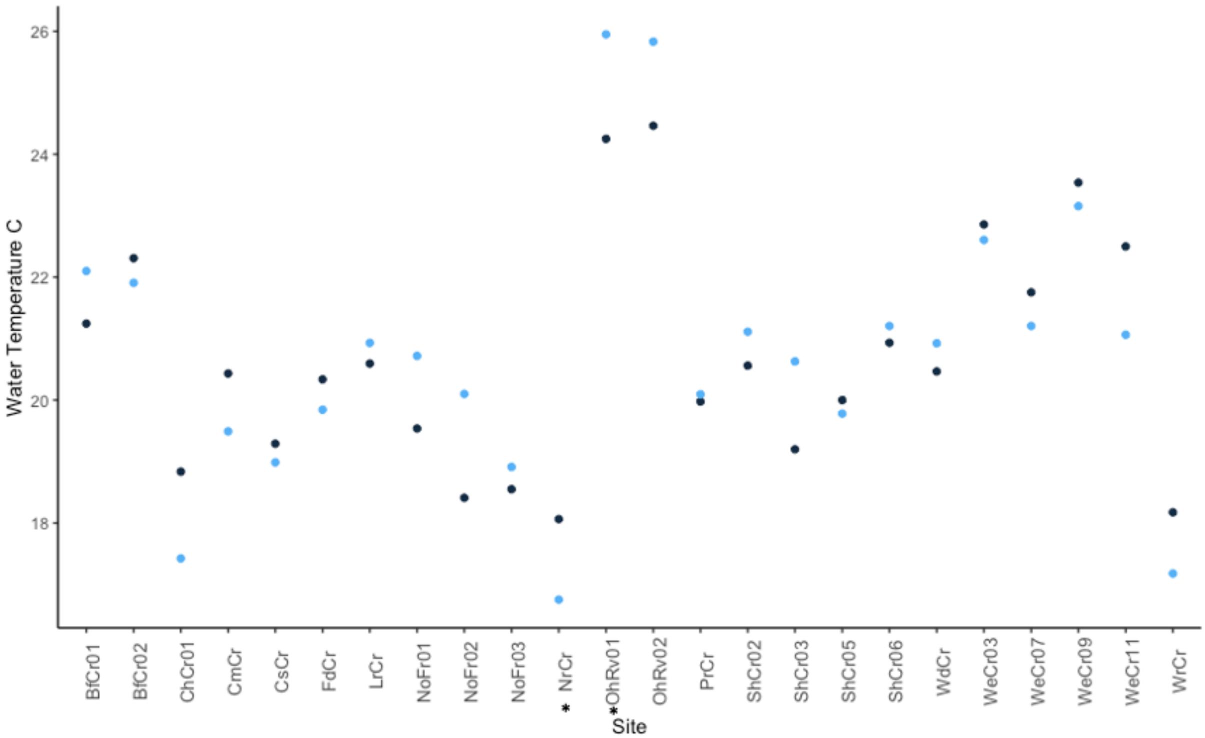
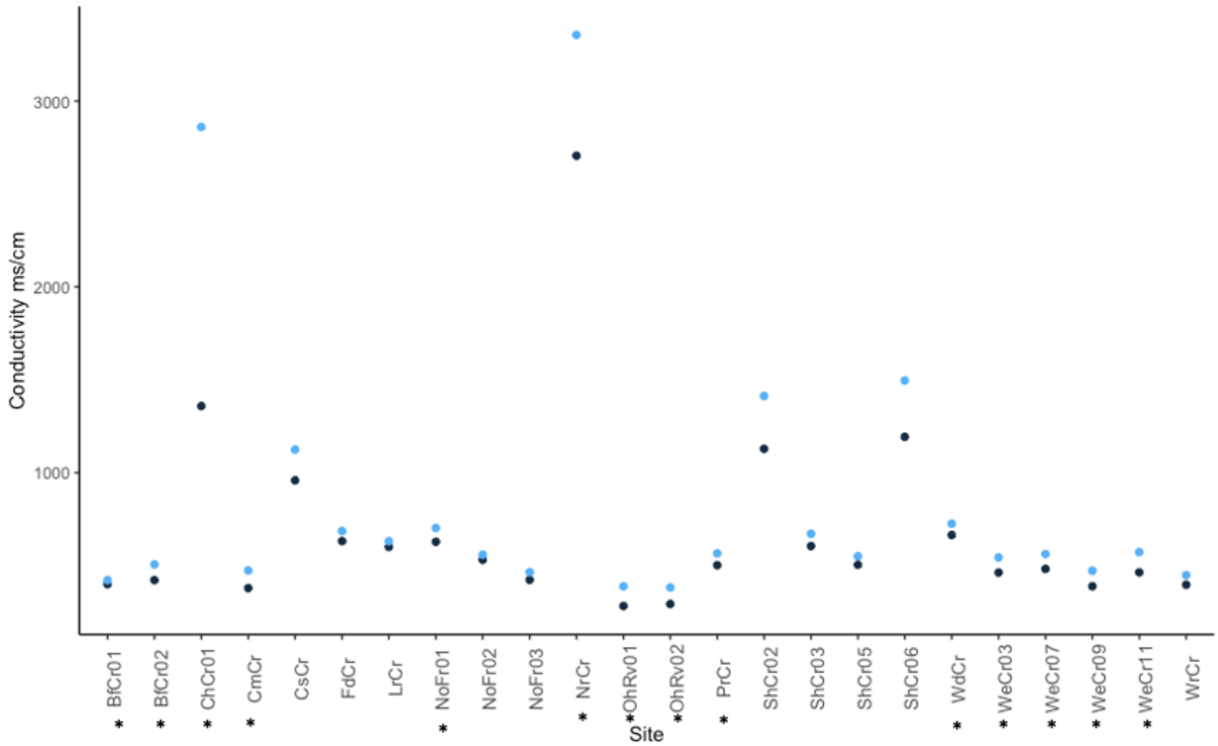
Table 1. Main watershed, stream, upstream watershed size, mean summer temperature and conductivity (SPC) for 24 water quality monitoring sites in the Upper Ohio River watershed near Wheeling, WV. Summer was defined as June 1st to September 30. Gray-bold indicates significant increases (P< 0.05) between summer 2019 and summer 2020, gray-bold and italicized indicates significant decrease between summer 2019 and summer 2020. An "*" indicates sites impacted by Acid Mine Drainage

Watershed	Stream	Watershed Size km^2	Mean Water Temp. 2019	Range Water Temp. 2019	Mean Water Temp. 2020	Range Water Temp. 2020	Mean SPC 2019	Range SPC 2019	Mean SPC 2020	Range SPC 2020
Buffalo Creek	Castlemans Run	44	20.4	18.9 - 22	19.5	14 - 24.6	378.8	291.5 - 429.9	473.6	399.6 - 516.5
	Buffalo Creek	291	21.2	15.6 - 24.2	22.1	16 - 27.9	**399.7**	359.1 - 430.5	**421.7**	303 - 482.8
	Buffalo Creek	364	22.3	16.9 - 25.5	21.9	17.6 - 27.6	**421.6**	378 - 457.5	**506.1**	430.9 - 623
Short Creek	Weidman Run	3	18.2	16 - 20	17.2	12.9 - 20.4	396.7	277.6 - 486.8	448.5	390.7 - 484.4
	North Fork Creek	4	18.6	14.1 - 21.4	18.9	14.9 - 23.8	423.4	360.8 - 495.2	464.3	384.2 - 847
	North Fork Creek	12	18.4	12.9 - 21.7	20.1	15.7 - 24.9	531.3	477.6 - 663	559.1	479.6 - 651
	Short Creek	12	20.0	16.4 - 22.5	19.8	14.2 - 22.6	504.5	448.8 - 630	550.4	406.4 - 645
	North Fork Creek	23	19.5	13.7 - 23.1	20.7	14.1 - 26.9	**628.3**	496.9 - 814	**702.2**	484.5 - 835
	Short Creek	45	19.2	13.7 - 22.8	20.6	16.4 - 23	605.4	509.2 - 674	671.0	557.5 - 840
	Short Creek	49	20.6	15.1 - 23.8	21.1	15.6 - 27.4	1128.6	653 - 2180	1412.6	717 - 3369
	Short Creek	54	20.9	17.8 - 23.9	21.2	17.1 - 25.1	1193.1	583- 1727	1496.1	820 - 2749
Wheeling Creek	National Road Creek*	< 1	***18.1***	16.7 - 19.5	***16.8***	13.7 - 20.1	**2706.2**	2049 - 3750	**3356.7**	922 - 4434
	Elm Run	2	20.5	15.1 - 24.5	20.9	17.9 - 23.1	**664.6**	592 - 760	**725.4**	635 - 808
	Waddles Run	3	20.3	18.9 - 21.6	19.8	15.1 -23.6	631.7	481.8 - 735	685.4	464.8 - 924
	Peters Run Creek	16	20.0	15.8 - 22.7	20.1	15.5 - 24.5	**502.1**	448.8 - 580	**565.5**	464.6 - 658
	Long Run Creek	18	20.6	15.9 - 23.9	20.9	15.7 - 26.6	600.8	481.6 - 751	631.2	501.5 - 777
	Wheeling Creek	160	22.5	18.8 - 24.2	21.1	16.3 - 24.6	**463.7**	304.3 - 622	**572.7**	436 - 701
	Wheeling Creek	161	21.8	17.2 - 27.5	21.2	14.4 - 27.1	**482.2**	378.1 - 619	**562.1**	434.2 - 705
	Wheeling Creek	569	23.5	19.1 - 28.1	23.2	16.6 - 26.5	**388.5**	250.7 - 476.4	**472.3**	326 - 558
	Wheeling Creek	748	22.9	18.8 - 24.8	22.6	16.9 - 26	**462.6**	327.8 - 566	**544.0**	439.1 - 646
Direct Tributaries to Ohio River	Glenn's Run	4	18.8	16.6 - 20.4	17.4	13.7 - 20.8	**1358.5**	631 - 2457	**2860.8**	1126 - 5120
	Caldwell Creek	8	19.3	17.4 - 21.1	19.0	15.1 - 22.1	958.8	665 - 1261	1124.3	767 - 1783
Ohio River	Ohio River	> 131,573	**24.3**	19.6 - 26.7	**26.0**	20.6 - 29.4	**282.4**	190.2 - 409.9	**388.3**	325 - 443
	Ohio River	> 131,573	24.5	19.3 27.5	25.8	21.2 - 29.5	**293.1**	194 - 404.4	**381.9**	324.4 - 443.2

Supplemental Graphs



Supplemental 1. Mean summer water temperature at each site for each year. The light blue represents readings from 2020 and the dark blue is 2019. An "*" indicates sites that had significant differences between years according to a Wilcoxon Signed Range test.



Supplemental 2. Mean summer specific conductivity at each site for years 2019 and 2020. Light blue represents readings from 2020 and the dark blue is year 2019. An "*" indicates sites that had significant differences between year according to a Wilcoxon Signed Range test.