Minnesota Pollution Control Agency
Biological Monitoring Program

Examining Relationships Among Stream Temperature Variables and Fish Community Attributes in Warmwater Streams of the Minnesota River Basin

It is well documented that water temperature is important to the ecology of aquatic communities, however, relatively little information exists evaluating the effects of stream temperature change on fish community structure within warmwater streams. Fish community sampling was conducted and stream temperature data loggers were deployed in 27 warmwater streams in the Minnesota River Basin in the summer of 2003 in an effort to begin establishing relationships between stream temperature variables and fish community structure. Land use and other disturbance factors did appear to affect thermal characteristics as significant differences were observed between stream temperature variables of sites rated positively or negatively for disturbance. However, no temperature variable emerged as a reliable or consistent driver of fish community structure and biological condition, potentially due to the lack of an adequate disturbance gradient or that temperature tolerance limits were not exceeded. As more concurrent stream temperature and fish community data becomes available perhaps relationships will emerge establishing stream temperature as an important driver of fish community structure within warmwater streams of Minnesota.

Introduction

Stream temperature is influenced by a complex interaction between external factors (air temperature, groundwater, precipitation, etc.) and stream physical structure (channel and floodplain morphology, riparian vegetation structure, etc.)(Poole and Berman 2001). Human activities such as dams, channel engineering, and land use changes can alter the factors that influence stream temperature.

Stream temperature directly influences the physiology, life history traits, and distribution patterns of aquatic biota (Wehrly et al. 2003). The effects of stream temperature change on coldwater fish species is well documented (McCullough 1999) and thermal requirements for numerous warmwater fish species have also been identified (Eaton et al. 1995). However, little information exists on the effect of increasing stream temperature within warmwater streams on fish community structure.

The purpose of this study was to begin exploring relationships between stream temperature variables and fish community attributes in warmwater streams of the Minnesota River Basin. This is an initial attempt to evaluate stream temperature as a potential stressor of biological condition in warmwater streams.

Figure 1. -- Location of sampling sites, watershed boundaries, and land use within the Minnesota River Basin of Minnesota.

Methods

A geographic information system (GIS) was used to select potential sites across a range of human disturbance, from minimal to severe. Each potential site was rated by examining the extent and proximity of disturbance factors at the reach and watershed scale. Factors considered in the rating process included: disturbed land use (agricultural, developed, rangeland, mining), stream channelization or ditching, municipal or industrial point sources, animal feedlots, and riparian zone condition. Sites were rated relative to the condition of other Minnesota River Basin streams of a similar size. Thirteen positively rated (i.e. relatively low disturbance) and 14 negatively rated (i.e. relatively high disturbance) sites were selected. The drainage areas of watersheds ranged from 7 mi^2 to 455 mi^2 (Table 1).

Temperature data loggers (Onset HOBO Water Temp Pro) were deployed in all 27 warmwater streams between May 20 and June 4, 2003. An attempt was made to position the temperature loggers out of direct sunlight in flowing water of intermediate depth. Stream temperature was recorded every ten minutes from the time they were deployed until they were collected, which ranged from July 21 to September 9, 2003.

Fish Sampling

Fish communities were sampled by electrofishing (pulsed DC) during base-flow conditions. The length of the reach needed to collect a representative sample of fish followed guidance provided by Lyons (1992). One pass was made in an upstream direction at each site, sampling all available habitat types in the proportion that they occurred. All fish were identified to species and counted. A length range and batch weight was recorded for each species. External anomalies were also noted. See MPCA "Fish Community Sampling Protocol for Stream Monitoring Sites" (www.pca.state.mn.us/water/biomonitoring/sf-sop-fish.pdf) for specific methods.

Analysis

Data obtained from the temperature loggers were used to calculate the following stream temperature variables for each site: average daily, minimum, and maximum temperature for the months of June, July, and August; average daily fluctuation for the months of June, July, and August; average summer (June-August) daily, minimum, and maximum temperature; and average summer daily, weekly, and monthly fluctuation in temperature (calculated as the average of maximum daily, weekly, or monthly temperature minus minimum daily, weekly, or monthly temperature for June-August data).

Index of Biological Integrity (IBI: Karr 1981) scores were calculated for each site using the IBI developed for stream fish communities of the Minnesota River Basin by Bailey et al. (1993). The IBI incorporated 13 attributes (termed metrics) of the fish community related to species richness and composition, trophic structure and reproductive function, and fish

Stream Name	MPCA Site #	Drainage (sq. mi.)	IBI Score	GIS Rating	% Water	% Forest	% Agriculture	% Developed	% Disturbed
N. Fork Nine Mile Creek	03MN058	10.8	31	-	7.4	3.4	0.0	89.2	89.2
County Ditch # 22	03MN077	12.3	31	-	15.3	8.7	68.3	7.7	76.0
County Ditch # 27	03MN055	12.7	17	-	2.9	1.2	92.0	3.8	95.9
Perch Creek tributary	03MN064	15.7	34	-	1.2	1.6	92.6	4.5	97.1
Judicial Ditch # 10	03MN049	40.9	22	-	5.5	1.6	92.4	0.6	93.0
Hawk Creek	03MN007	44.3	29	-	17.3	5.5	70.1	7.1	77.2
Judicial Ditch #30	03MN031	58.6	26	-	1.6	1.6	93.7	3.1	96.8
Judicial Ditch # 1A	03MN026	76.1	24	-	2.1	1.8	95.5	0.6	96.1
Middle Br. Rush River	03MN024	82.2	26	-	1.3	2.1	95.2	1.5	96.6
S. Br. Rush River	03MN025	83.4	31	-	3.2	2.3	93.7	0.8	94.5
W. Fork Beaver Creek	03MN018	97.5	46	-	3.4	1.7	94.1	0.7	94.9
N. Br. Rush River	03MN027	98.9	24	-	4.9	2.5	91.4	1.3	92.7
Sleepy Eye Creek	03MN032	273.1	48	-	1.6	1.5	96.4	0.5	96.9
Rush River	03MN028	404.9	30	-	2.8	3.9	92.3	1.0	93.3
Dutch Charley Creek	03MN035	6.6	19	+	11.7	2.2	86.0	0.1	86.1
Echo Creek	03MN057	15.6	19	+	0.5	2.2	96.5	0.8	97.3
Barney Fry Creek	03MN076	26.4	41	+	3.5	6.0	90.1	0.5	90.6
Lazarus Creek	03MN046	31.4	29	+	11.9	2.9	85.1	0.1	85.2
Dutch Charley Creek	03MN023	54.6	29	+	3.6	2.7	93.4	0.3	93.7
Lac Qui Parle River tributary	03MN044	69.4	31	+	10.2	2.7	86.6	0.5	87.0
Carver Creek	03MN030	71.5	36	+	26.3	12.8	58.4	2.5	60.9
S. Br. Yellow Medicine River	03MN038	76.8	46	+	6.5	2.0	91.0	0.4	91.5
Nicollet Creek	03MN069	78.6	19	+	29.0	5.3	64.6	1.0	65.7
Little Chippewa River	03MN004	108.7	20	+	21.2	5.3	73.0	0.5	73.5
Florida Creek	03MN052	149.0	28	+	6.8	2.4	90.6	0.2	90.8
N. Fork Yellow Bank River	03MN053	208.0	34	+	4.8	2.3	92.3	0.6	92.9
Yellow Bank River	03MN054	455.4	34	+	5.9	2.1	91.6	0.5	92.1

Table 1. Site characteristics and watershed land use.

abundance and condition. Because the drainage area of a stream is an important variable influencing fish community structure, the metrics used and their scoring criteria may vary between sites depending on its drainage area. When the metrics are summed together the resulting index score characterizes the underlying biological integrity or "health" of a site (Karr et al. 1986).

Spearman Rank Correlation Coefficients were calculated to determine if there was a significant relationship between stream temperature variables, IBI scores, and the individual metrics that comprised the IBI. For variables that were significantly correlated with drainage area the residuals from linear regression analyses were used in the correlations to minimize the effect. Significant differences between positively and negatively rated sites were identified with a Mann-Whitney U test.

Results

All stream temperature variables, except those describing fluctuations between time periods, were positively correlated with drainage area. All were significant to the .05 level except average June daily maximum ($p<.10$). Seven of the thirteen metrics that were used in the IBI were also significantly correlated ($p < .05$) with drainage area.

Of the 252 possible correlations between temperature variables (18) and fish community attributes (14), only 11 were significant ($p<.05$). No apparent pattern emerged as the 11 significant results were spread between 7 different temperature variables and 5 fish metrics. Fish metrics that elicited a significant response to temperature variables (and the number of temperature variables that a significant response was observed) included: the number of minnow species (4), proportion of individuals that are top carnivores (3), proportion of individuals that are specialized insectivores (2), number of sucker species and number of fish per minute (1 each)(Table 2). However, only the four relationships observed with the top carnivore and sucker metrics were in the predicted direction. That is, the fish metric value declined as the stream temperature variable increased.

Temperature Variables	Minnow* (r_s)	(p)	Sucker* (r_s)	(p)	SpecInsectPct (r_s)	(p)	TopCarnPct* (r_s)	(p)	NumPerMin (r_s)	(p)
JuneAvg*	0.036	> 0.5	-0.340	< 0.1	0.392	**< .05**	-0.314	< 0.2	-0.012	> 0.5
JuneAvgMin*	-0.183	< 0.5	-0.230	< 0.5	0.427	**< .05**	-0.153	< 0.5	-0.153	< 0.5
JuneAvgMax*	0.195	< 0.5	-0.259	< 0.2	0.308	< 0.2	-0.344	< 0.1	0.105	> 0.5
JuneAvgVar	0.426	**< .05**	0.012	> 0.5	-0.075	> 0.5	-0.140	< 0.5	0.231	< 0.5
JulyAvg*	0.182	< 0.5	-0.200	< 0.5	0.068	> 0.5	-0.151	< 0.5	-0.073	> 0.5
JulyAvgMin*	-0.125	> 0.5	-0.037	> 0.5	0.200	< 0.5	0.142	< 0.5	-0.234	< 0.5
JulyAvgMax*	0.350	< 0.1	-0.344	< 0.1	0.039	> 0.5	-0.350	< 0.1	0.130	> 0.5
JulyAvgVar	0.605	**< .002**	-0.332	< 0.1	-0.100	> 0.5	-0.558	**< .005**	0.421	**< .05**
AugAvg*	0.279	< 0.2	-0.282	< 0.2	0.021	> 0.5	-0.185	< 0.5	-0.070	> 0.5
AugAvgMin*	0.199	< 0.5	-0.075	> 0.5	0.088	> 0.5	0.090	> 0.5	-0.070	> 0.5
AugAvgMax*	0.191	< 0.5	-0.142	< 0.5	0.151	< 0.5	-0.176	< 0.5	-0.124	> 0.5
AugAvgVar	0.057	> 0.5	-0.138	< 0.5	0.065	> 0.5	-0.288	< 0.2	-0.089	> 0.5
SummerAvg*	0.184	< 0.5	-0.203	< 0.5	0.192	< 0.5	-0.187	< 0.5	-0.041	> 0.5
SummerAvgMin*	-0.034	> 0.5	-0.109	< 0.5	0.237	< 0.5	0.042	> 0.5	-0.136	> 0.5
SummerAvgMax*	0.298	< 0.2	-0.242	< 0.5	0.127	> 0.5	-0.297	< 0.2	0.055	> 0.5
DailyAvgVar	0.493	**< .01**	-0.178	< 0.5	-0.056	> 0.5	-0.430	**< .05**	0.269	< 0.2
WeeklyAvgVar	0.456	**< .02**	-0.275	< 0.2	-0.087	> 0.5	-0.438	**< .05**	0.194	< 0.5
MonthlyAvgVar	0.380	< 0.1	-0.420	**< .05**	-0.133	> 0.5	-0.344	< 0.1	0.134	< 0.5

Table 2. Spearman rank correlations (r_s) and significance values (*p*) for fish community attributes that demonstrated at least one significant relationship with stream temperature variables. Variables marked with an asterisk indicate variables in which residual values were used in the correlations. Bold values indicate a significant correlation (p<.05).

While no one temperature variable emerged as consistently significant, 9 of the 11 significant results involved stream temperature variables relating fluctuations over time. Indicating that less stable temperature regimes may be an important factor for some fish community attributes. Of these, the average daily fluctuation in July temperature elicited the most significant relationships with fish community attributes (3).

Six of the 18 temperature variables were significantly different (p < .05) between rating groups (Figure 2). In each case, stream temperature variables for the group of sampling sites rated positively had lower or less variable values. The proportion of individuals as omnivores was the only fish attribute that exhibited a significant difference (p < .035) between rating groups. In addition, IBI scores did not differ significantly between rating groups.

Discussion

Our results suggest that increased temperature fluctuations may influence fish community structure more than temperature variables relating averages, minimums, or maximums. Wehrly et al. (2003) observed lower species richness and standing stock at higher temperature fluctuations (average weekly July fluctuation) within warmwater streams. The majority of significant relationships (9 of 11) between temperature and fish metrics involved temperature fluctuation variables. The number of minnow species appears to be the most influenced, as 4 of 6 temperature fluctuation variables elicited a significant response. In each case, the number of minnow species increased with increasing temperature fluctuation. The number of sucker species declined as summer average monthly fluctuation increased, number of fish per minute increased as July average daily fluctuation increased, and the proportion of individuals as top carnivores decreased as July average daily, summer average daily, and summer average weekly fluctuation increased. July average daily fluctuation demonstrated a significant correlation with 3 fish attributes, displaying the most promise of the stream temperature variables analyzed to be an important driver of fish community structure.

An attempt was made to rate sites positively or negatively based on disturbance factors within the context of the Minnesota River Basin. Even though sites rated positively had considerable amounts of disturbance, significant differences were detected for 6 stream temperature variables between rating groups. In each case, stream temperature was significantly higher or more variable at sites rated negatively for disturbance, suggesting that land use can influence stream temperature. However, the proportion of individuals as omnivores was the only fish attribute to significantly differ between rating groups, indicating that the disturbance rating did not explain enough of the variation in fish community structure and that the differences seen in temperature variables were not enough to influence fish community structure.

Stream temperature is only one of many variables that interact in a complex manner to determine the suitability of a stream for aquatic biota. Natural variations in the chemical, physical, and morphological characteristics of streams strongly influence the presence and abundance of stream fishes (Rankin 1989). Variability is increased by the effects of human activities such as; chemical pollutants from municipal and industrial point source discharges; agricultural runoff of sediment, nutrients, and pesticides; hydrologic alteration from stream channelization, dams, and artificial drainage; and habitat alteration from agricultural, urban, and residential encroachment.

It is difficult to find watersheds in the Minnesota River Basin that are minimally impacted to serve as baseline or reference data. In order to better detect changes in species assemblage structure, sampling sites should reflect an adequate disturbance gradient, from minimal to severe. Given the pervasiveness of land use modifications in the watersheds of study sites, where the amount of disturbed land use averaged 89% (range 61-97%), it is likely that significant shifts in species assemblage and thermal characteristics had already occurred. This might explain why significant differences were not detected between rating groups for fish attributes and IBI score.

An additional reason for stream temperature not emerging as a more conclusive driver of fish community structure may be that temperatures observed in this study did not exceed tolerance thresholds. Bell (1991) reported that fish do not move away from high temperature areas (particularly warmwater fish) until the temperature reaches their upper tolerance level. None of the temperatures observed in this study exceeded upper thermal tolerance limits (based on maximum weekly mean temperatures) for warmwater fish species as reported in

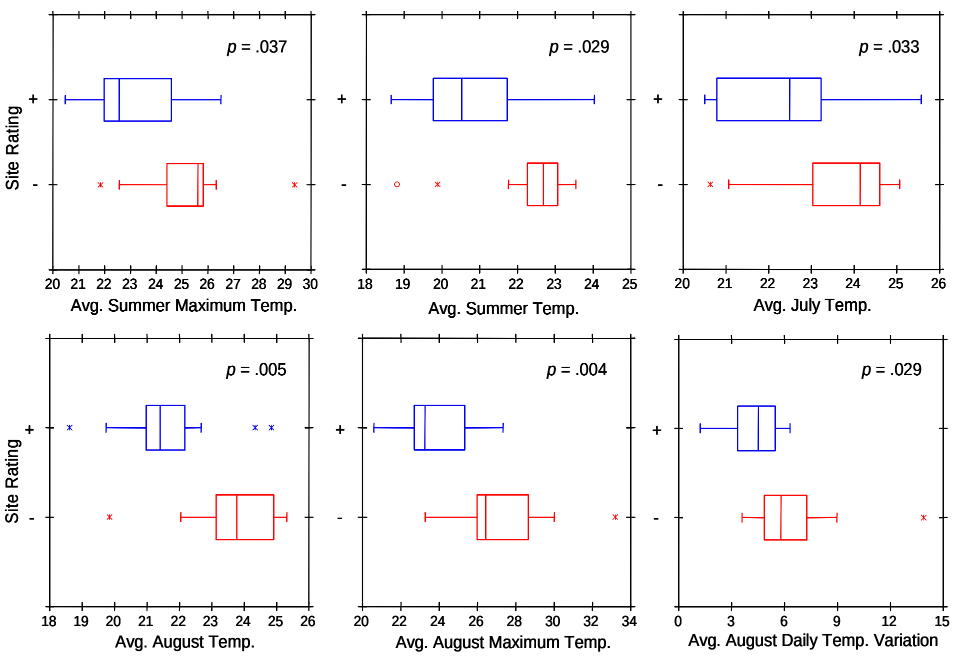

Figure 2. Box and whisker graphs of water temperature variables that differed significantly between sites rated positively or negatively for disturbance. The center vertical line denotes the median value, box boundaries mark the first and third quartiles, whiskers are the range of values within the inner fence (1.5 times midrange). Values between the inner and outer fences (3 times midrange) are plotted with asterisks and empty circles are far outside values beyond the outer fence. P-value indicates significance level of Mann-Whitney U Test between rating groups.

Eaton et al. (1995). In addition, in no case did stream temperatures exceed a daily average temperature of 30˚ C, which is the state of Minnesota water quality standard necessary to permit the propagation and maintenance of a healthy aquatic community in warmwater streams (class 2B).

Although thermal associations for individual fish species have been documented and used to classify fish into coldwater, coolwater, and warmwater categories (Hokanson 1977; Eaton et al. 1995; Lyons 1996) this information has limited use for evaluating the effects of stream temperature change on species assemblage structure within warmwater streams. A better understanding of the relationship between fish community structure and varying thermal characteristics within warmwater streams is necessary for more effective ecological assessment and identification of biological stressors. As the Minnesota Pollution Control Agency continues to collect temperature and fish community data in streams throughout Minnesota, perhaps relationships will emerge establishing stream temperature as an important driver of fish community structure in warmwater streams.

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December 2005