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Teresa Newton, Jennifer Sauer & Byron Karns

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WATER AND SEDIMENT TEMPERATURES AT MUSSEL BEDS IN THE UPPER MISSISSIPPI RIVER BASIN

Teresa Newton

U.S. Geological Survey
Upper Midwest Environmental Sciences Center, La Crosse, WI 54603 U.S.A.
email: tnewton@usgs.gov

Jennifer Sauer

U.S. Geological Survey
Upper Midwest Environmental Sciences Center, La Crosse, WI 54603 U.S.A.
email: jsauer@usgs.gov

Byron Karns

National Park Service
St. Croix National Scenic Riverway, St. Croix Falls, WI 54024 U.S.A.
email: byron_karns@nps.gov

ABSTRACT

Native freshwater mussels are in global decline and urgently need protection and conservation. Declines in the abundance and diversity of North American mussels have been attributed to human activities that cause pollution, water-quality degradation, and habitat destruction. Recent studies suggest that effects of climate change may also endanger native mussel assemblages, as many mussel species are living close to their upper thermal tolerances. Adult and juvenile mussels spend a large fraction of their lives burrowed into sediments of rivers and lakes. Our objective was to measure surface water and sediment temperatures at known mussel beds in the Upper Mississippi (UMR) and St. Croix (SCR) rivers to estimate the potential for sediments to serve as thermal refugia. Across four mussel beds in the UMR and SCR, surface waters were generally warmer than sediments in summer, and were cooler than sediments in winter. This suggests that sediments may act as a thermal buffer for mussels in these large rivers. Although the magnitude of this effect was usually <3.0°C, sediments were up to 7.5°C cooler at one site in May, suggesting site-specific variation in the ability of sediments to act as thermal buffers. Sediment temperatures in the UMR exceeded those shown to cause mortality in laboratory studies. These data suggest that elevated water temperatures resulting from global warming, thermal discharges, water extraction, and/or droughts have the potential to adversely affect native mussel assemblages.

KEY WORDS Native freshwater mussels, Water temperature, Mississippi River, Unionids, Climate change

INTRODUCTION

Anthropogenic warming is changing thermal regimes in freshwater systems. The effects of climate change have been seen in nearly every ecosystem; however, aquatic systems may be especially sensitive to thermal stress because of human alterations such as dams and diversions, deforestation, urbanization, and channelization (Hester & Doyle, 2011). In aquatic systems, climate change can alter thermal regimes, reduce ice cover, change stream flows, increase water development, and increase salinity (Rahel & Olden, 2008). It is well established that elevated temperatures can adversely affect aquatic organisms. For example, elevated water temperatures have been associated with increased energy requirements of young-of-the-year fishes (McDonald et al., 1996), reduction in available habitat for stream biota (Eaton & Scheller, 1996), increased probability of outbreaks of toxic algal blooms (Gilbert, 1996), and more rapid life cycle completion in stream invertebrates (Wilhelm & Schindler, 2000).

Native freshwater mussels are long-lived, benthic filter-feeding organisms that provide important ecological services to aquatic systems (Vaughn & Hakenkamp, 2001; Spooner & Vaughn, 2008). Mussels are frequently found in dense, species-rich assemblages called mussel beds. However, many river systems have lost substantial numbers of native mussel species in the past century. For example, about 20 mussel species have been functionally lost from the Upper Mississippi River basin, and many others are state or federally listed (Newton et al., 2011). Losses in species richness and biomass appear to result from varied anthropogenic effects including impoundments, water management alterations, invasive species, changing land use, pollution and most recently, climate change (Hastie et al., 2003; Strayer et al., 2004; Galbraith et al., 2010).

The mechanisms by which elevated water temperatures may influence mussel assemblages are poorly known, largely because thermal tolerance has been studied for few species. To our knowledge, quantitative data on lethal temperatures is limited to <15 species (~5% of the 300 known species in North America). Most studies on thermal tolerance in mussels result from acute laboratory studies with early life stages. These studies generate an LT50 which is the median lethal temperature that causes mortality in 50% of the individuals over a specified time interval. For example, 4-d LT50s across 11 species of juveniles ranged from 32.5 to 38.8°C (Pandolfo et al., 2010; Archambault et al., 2012). In chronic tests, Ganser et al. (in press) observed 28-d LT50s that ranged from 25.3 to 30.3°C among three species of juveniles.

Considerably less is known about the thermal tolerance of adult mussels. The maximum temperature at which five species of mussels were observed in the River Rhine ranged from 24 to 28°C, even though water temperatures can reach 32°C in this system (Verbrugge et al., 2012). Estimated critical thermal maxima (the temperature at the onset of behavioral incapacitation) in three species of mussels (*Alasmidonta varicosa*, *Elliptio complanata*, and *Strophitus undulatus*) ranged from 39.1 to 42.7°C (Galbraith et al., 2012). Bartsch et al. (2000) suggest that adults of three species (*Elliptio dilatata*, *Quadrula pustulosa*, *Lampsilis cardium*) were remarkably resistant to thermal shock.

Although vertical movement into sediments has been described as an important behavior in mussels (Haag, 2012), we know little about this behavior — especially in rivers. Adult mussels burrow as deeply as 25 cm, but usually burrow <10 cm (Balfour & Smock, 1995; Schwalb & Pusch, 2007; T.J. Newton, unpublished data). We know considerably less about burrowing activities in juveniles. In captivity, juveniles typically burrowed <1 cm (Yeager et al., 1994). Burrowing behavior often varies with biological (e.g., reproduction, Amyot & Downing, 1998; Eads & Levine, 2013) and environmental parameters (e.g., season, flow, substrate, Di Maio & Corkum, 1997). Many species of adults can be found near the sediment surface in spring and summer but may burrow more deeply in fall and winter (Amyot & Downing, 1997; Schwalb & Pusch, 2007). While adult mussels exhibit vertical migration patterns in the sediment with periods at, above, or below the sediment surface, juveniles appear to remain burrowed in sediments for the first few years of life (Cope et al., 2008).

The ability to accurately assess the thermal tolerances of multiple life stages of mussels in the wild is limited by the inadequate understanding of the background thermal regimes in river sediments — the environment in which mussels reside for most of their lives. Our objective was to measure surface water and sediment temperatures at known mussel beds in the Upper Mississippi (UMR) and St. Croix rivers (SCR) to estimate the potential for sediments to serve as refugia during times of thermal stress.

METHODS

We selected four mussel beds in the UMR and four beds in the SCR that had high mussel density, high species richness, and contained a range of age classes including young individuals of several species (Fig. 1). The beds at sites 1-6 were located in the border of the main navigation channel, while the beds at sites 7 and 8 were in large side channels. The mussel beds ranged from ~22,000-222,000 m^2 in size. The substrate was predominately medium to coarse sands in all beds. These sites are representative of areas where dense and diverse mussel assemblages typically occur in these rivers.

We placed submersible temperature data loggers (iBCod, Alpha Mach, Inc., Mont St-Hilaire, Quebec, Canada) at 5-7 locations in each mussel bed (Table 1). The locations were chosen to span the area encompassed by each mussel bed. Temperature loggers were mounted on Trex® composite stakes in a manner that allowed them to be deployed in three vertical strata at a single point: 5 and 15 cm below the sediment-water interface and in the water column, 10 cm above the sediment-water interface (hereafter referred to as surface water stratum, Fig. 2). Due to cost, water column loggers were placed on only two of the samplers (selected at random) at each site. Temperature loggers were initially deployed in the summer of 2010; retrieved, downloaded and re-deployed in the fall of 2010 and spring of 2011; and retrieved and downloaded in the fall of 2011. Due to limited memory, temperature loggers were programmed to record temperatures hourly in the summer and fall and every three hours in the winter and spring. Because retrieval rates of temperature loggers were low (see below), detailed statistical analyses were not conducted. Rather, we examined the data for patterns in water and sediment temperatures over time and among depth strata. We estimated the deviation between surface water and sediment temperatures as the difference in temperature between surface water and the 5 or 15 cm sediment depth. If the deviation was >0, sediment temperatures were cooler than surface water temperatures.

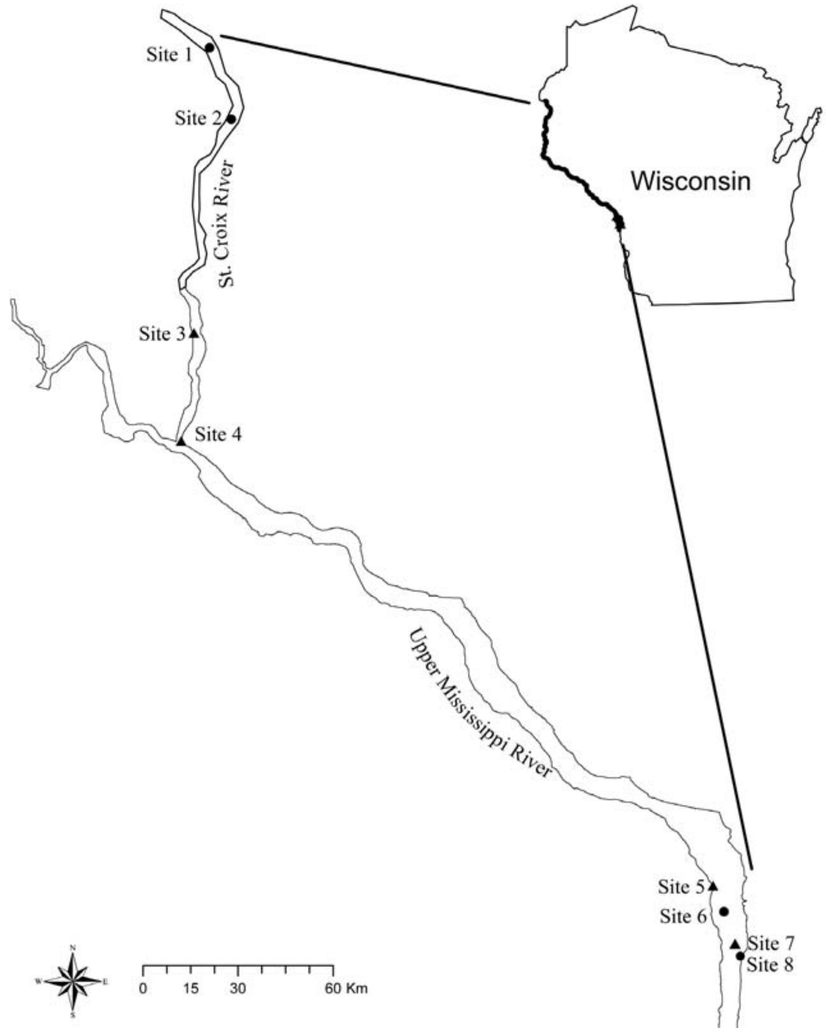

FIGURE 1

Map of locations where temperature recording data loggers were deployed in the St. Croix and Upper Mississippi rivers. Sites denoted by triangles had at least 10 months of surface water and sediment temperature data.

TABLE 1

Deployment of temperature data loggers (i.e., iBCod's) at known mussel beds in the St. Croix (sites 1-4) and Upper Mississippi (sites 5-8) rivers. Temperature loggers were deployed on stakes and each stake contained a data logger at 5 and 15 cm below the sediment-water interface. Each site also had two randomly placed data loggers that were 10 cm above the sediment-water interface.

Site	No. stakes deployed	Total no. iBCod's deployed	Date initially deployed[a]	Date of final retrieval	No. of iBCod's with <10 months of data	No. of iBCod's with ≥10 months of data
1	7	16	7-23-2010	7-20-2011	10	0
2	7	16	7-23-2010	7-20-2011	9	0
3	7	16	8-19-2010	10-4-2011	9	3
4	7	16	8-19-2010	10-5-2011	12	1
5	7	16	7-29-2010	10-20-2011	5	4
6	5	12	7-29-2010	10-20-2011	2	0
7	5	12	8-11-2010	10-19-2011	3	2
8	7	16	7-29-2010	10-19-2011	4	1

[a]sampling interval during summer and fall deployment was 1 hour; sampling interval during winter and spring deployment was 3 hours

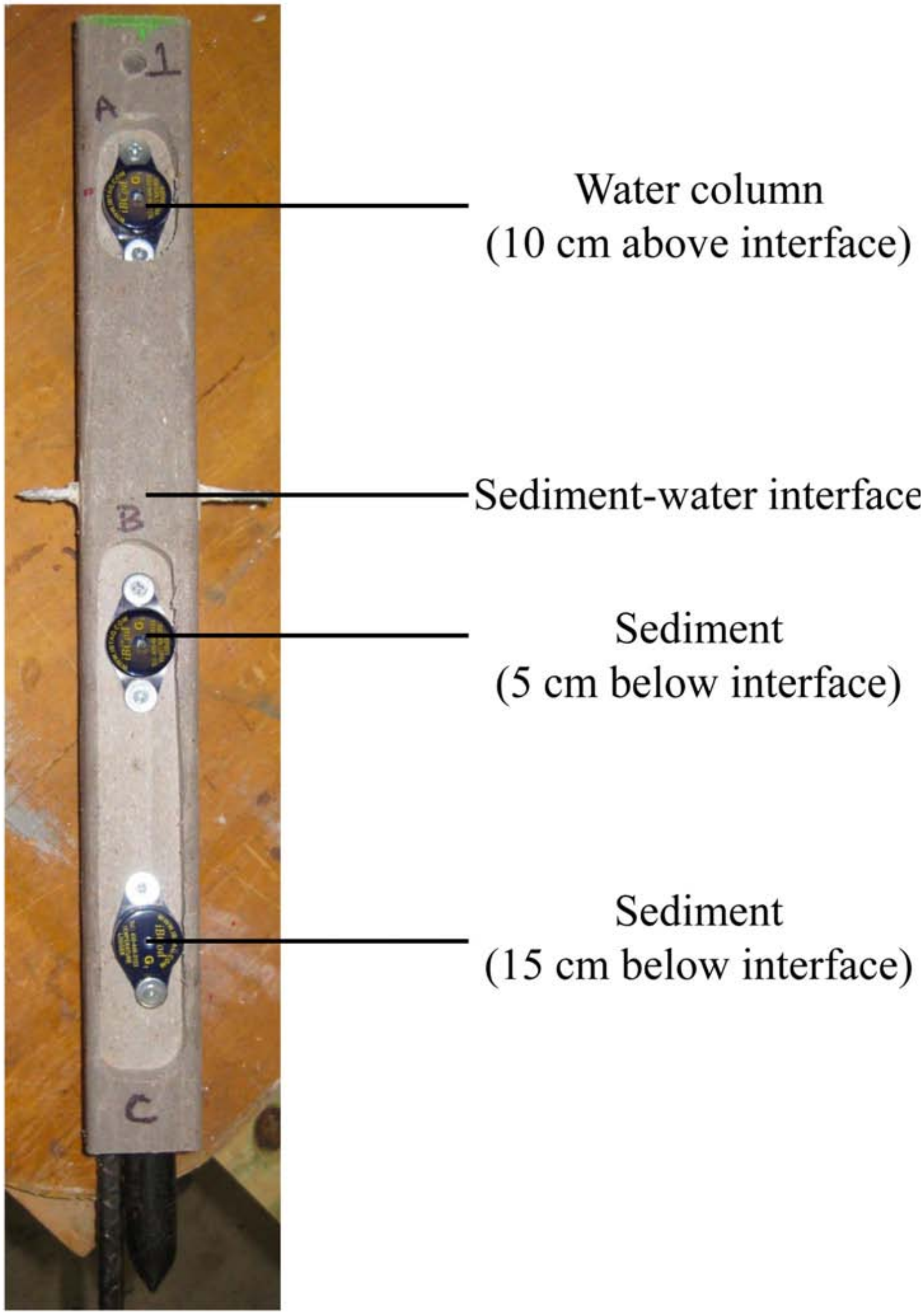

FIGURE 2

Schematic of stakes used to deploy temperature recording data loggers in the St. Croix and Upper Mississippi rivers.

RESULTS

We obtained data from few temperature loggers because retrieval rates were low due to high water and nearly half of the retrieved loggers experienced electrical malfunction (Table 1). However, we have at least 10 months of data for at least two of the depth strata from one stake at two mussel beds on the SCR and two mussel beds on the UMR (Table 2). Across these sites, surface waters were generally warmer than sediments from spring through fall and cooler than sediments in winter (Figs. 3 and 4). Temporal patterns were similar across sites, although sites in the UMR were ~1-2°C warmer in summer than sites in the SCR. From fall 2010 through spring 2011, mean temperatures ranged from 0 to 26°C in the surface water and 5 cm sediment stratum and from 0 to 25°C in the 15 cm sediment stratum (Table 3).

TABLE 2

Dates over which surface water and sediment temperature data were available at sites with known mussel beds in the St. Croix (SCR) and Upper Mississippi (UMR) rivers. Temperature loggers were deployed 10 cm above the sediment-water interface (surface) and at 5 and 15 cm below the sediment-water interface.

Site (River)	Depth strata	Dates	Approximate time interval
3 (SCR)	surface, 5 and 15 cm	8-20-2010 to 10-28-2010	2 mon
	surface and 5 cm	8-20-2010 to 6-6-2011	10 mon
4 (SCR)	surface, 5 and 15 cm	8-20-2010 to 6-12-2011	10 mon
	5 cm	8-20-2010 to 8-11-2011	12 mon
5 (UMR)	surface, 5 and 15 cm	7-30-2010 to 10-20-2011	15 mon
7 (UMR)	surface, 5 and 15 cm	8-12-2010 to 10-21-2010	2 mon
	5 and 15 cm	8-12-2010 to 7-5-2011	11 mon

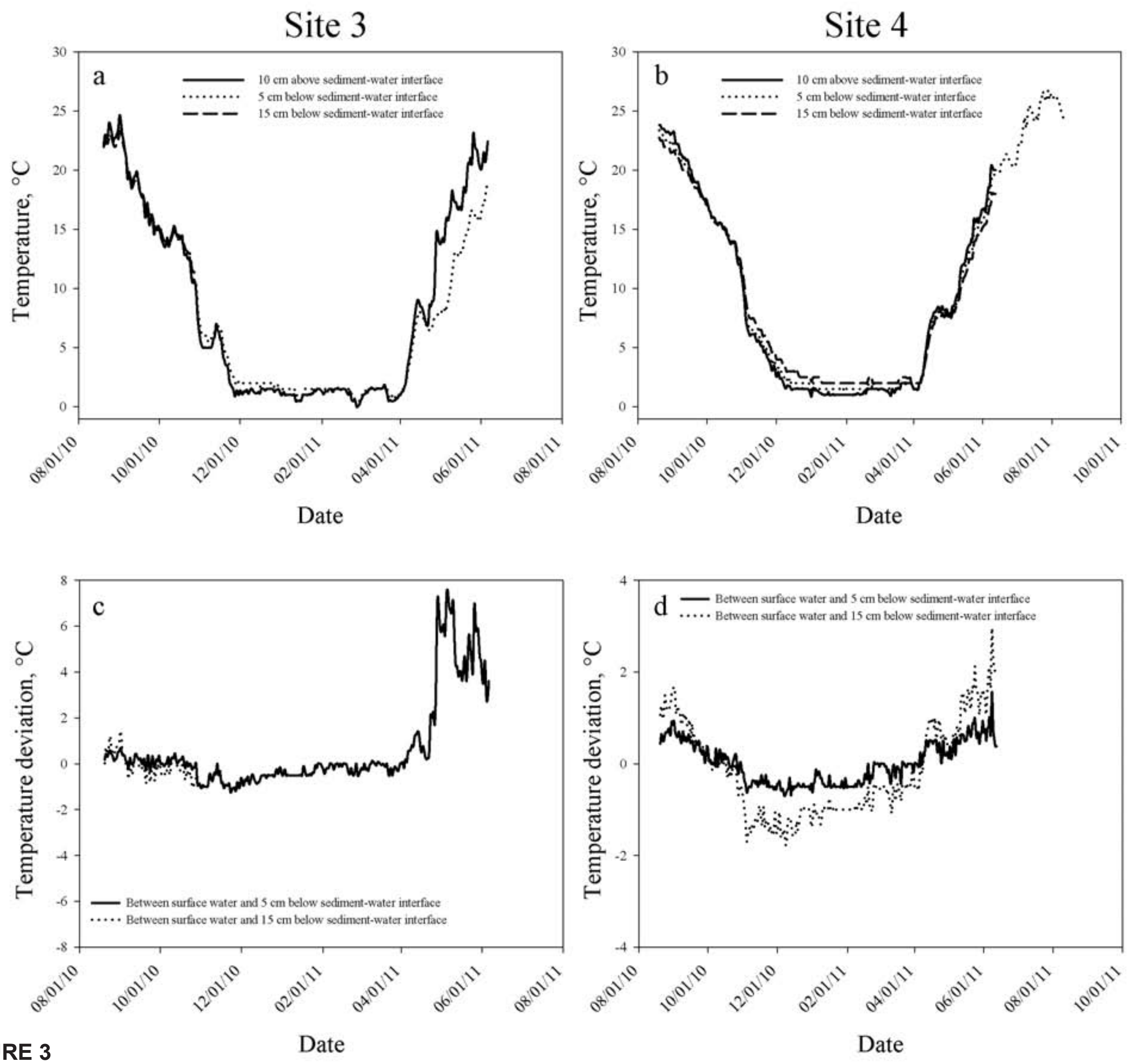

FIGURE 3

Temperature patterns in three strata (10 cm above the sediment-water interface and 5 and 15 cm below the sediment-water interface) and temperature deviations between surface and sediment strata from one stake at two sites with known mussel beds in the St. Croix River. A positive temperature deviation indicates that surface waters were warmer than sediments.

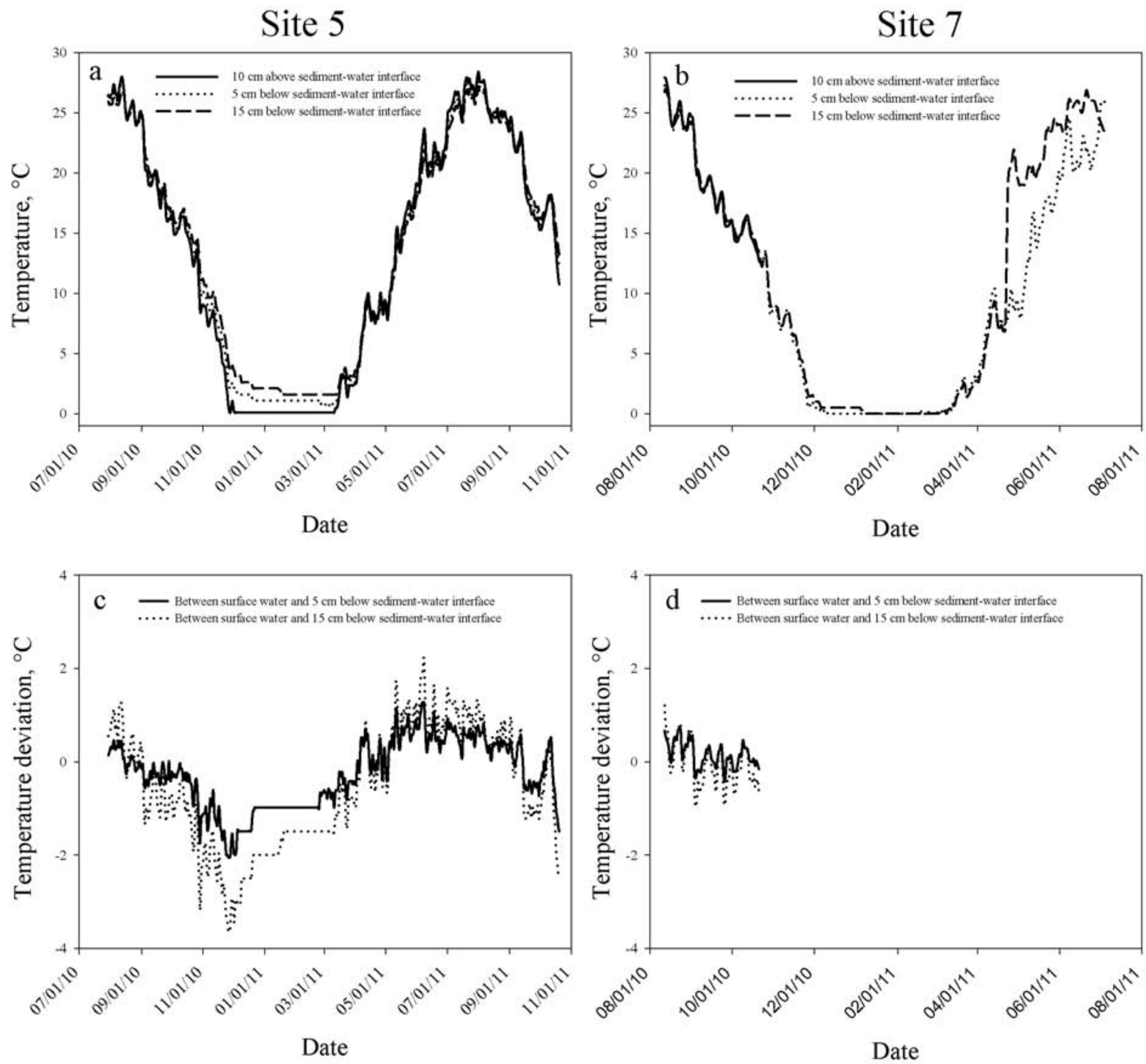

FIGURE 4

Temperature patterns in three strata (10 cm above the sediment-water interface and 5 and 15 cm below the sediment-water interface) and temperature deviations between surface and sediment strata from one stake at two sites with known mussel beds in the Upper Mississippi River. A positive temperature deviation indicates that surface waters were warmer than sediments.

Temperature deviations were variable among sites, ranging from 2.1°C warmer to 7.5°C cooler in the 5 cm stratum and from 3.6°C warmer to 2.9°C cooler in the 15 cm stratum relative to surface water (Figs. 3 and 4). On average, temperatures in the 5 cm stratum were 0.2 to 1.0°C warmer during fall, winter and spring and 0.5-4.0°C cooler during summer compared to surface water (Figs. 3 and 4). However, we observed a substantial deviation between surface water and the 5 cm sediment stratum (+7.5°C) at site 3 in the spring 2011 (Fig. 3c), presumably due to rapidly rising water temperatures in the spring (Fig. 3a). On average, sediment temperatures were 0.8 to 1.8°C warmer during fall, winter and spring and 0.6-0.7°C cooler during summer in the 15 cm stratum relative to surface water (Figs. 3 and 4).

We hypothesized that surface water temperatures might be more variable than sediment temperatures, however, we found little evidence for this in the present study. For example, over the time period of July 2010 to July 2011 at site 5, the mean coefficient of variation (CV) of temperatures in surface water was 69%. Similarly, the CV was 65% and 61% at 5 and 15 cm below the sediment-water interface, respectively.

TABLE 3

Descriptive statistics of surface water and sediment temperature (°C) at sites with known mussel beds in the St. Croix (SCR) and Upper Mississippi (UMR) rivers during August 20, 2010 to June 5, 2011. Temperature loggers were deployed 10 cm above the sediment-water interface (surface) and at 5 and 15 cm below the sediment-water interface. Deviation is the difference in temperature between surface water and the 5 or 15 cm sediment depth. If a given depth stratum is not listed, there were not data over the entire time interval.

Depth stratum	Mean	SD	Range
		Site 3 (SCR)	
surface	8.2	7.9	0 to 24.6
5 cm	7.6	7.0	0.5 to 23.9
5 cm deviation	0.6	2.0	-1.3 to 7.5
		Site 4 (SCR)	
surface	8.0	7.4	0.9 to 23.8
5 cm	8.0	7.1	1.2 to 23.4
15 cm	8.2	6.7	2.0 to 22.8
5 cm deviation	-0.1	0.4	-0.7 to 1.0
15 cm deviation	-0.2	1.0	-1.8 to -2.1
		Site 5 (UMR)	
surface	7.9	8.0	0.1 to 26.0
5 cm	8.4	7.5	0.7 to 25.9
15 cm	8.9	7.3	1.6 to 25.4
5 cm deviation	-0.5	0.7	-2.1 to 1.1
15 cm deviation	-1.1	1.2	-3.6 to 1.8
		Site 7 (UMR)	
5 cm	7.8	7.9	0 to 25.2
15 cm	9.0	9.0	0 to 25.1

DISCUSSION

Although the data set is limited, our data suggest that river sediments may act as a thermal buffer for native mussels during winter and summer in mussel beds in the UMR basin. In summer, temperatures were 0.5 to 40°C cooler in the 5 cm sediment stratum which would provide mussels a refuge from warm summer temperatures, which may be important during this time of active movement and reproduction in many species. In winter, warmer temperatures in sediments (range, 0.2-1.8°C) may allow mussels to live at temperatures closer to groundwater and provide a refuge from cold winter temperatures, especially in shallow waters. The ability of mussels to move vertically in response to temperature has been observed in other studies. In mesocosms, *Actinonaias ligamentina* burrowed into sediments during periods of high water temperatures, presumably to seek out cooler interstitial waters (Allen & Vaughn, 2009). Amyot & Downing (1997) reported that vertical migration of *Elliptio complanata* in a Canadian lake was significantly correlated with water temperature. However, the ability of sediments to act as thermal buffers may be site-specific and more research on those variables (e.g., particle size, ground water influence, water content) that influence vertical thermal profiles is needed.

Although the magnitude of the differences between surface water and sediment temperatures may not seem large, laboratory studies have shown that the average difference between temperatures that killed 5% (LT05) and 50% (LT50) of juveniles was only 4-5°C (Pandolfo et al., 2010; Ganser et al., in press). Given that most of our sites were in channel border areas characterized by coarse sand and some hyporheic flow, we might not expect to see much variation in surface water temperature among depth strata. The fact that we observed up to a 7°C differential between surface water and sediment temperature in a river as large as the UMR, with high thermal inertia, suggests that similar differences in smaller rivers may be considerable. Thus, small changes in sediment temperatures (relative to surface waters) may provide mussels an opportunity to alleviate thermal stress.

The temperatures observed in sediments in mussel beds in the UMR basin can exceed those shown to cause mortality in the laboratory. For example, chronic laboratory exposures of three species of juveniles resulted in 28-d LT50s that were 25.3°C in *Lampsilis siliquoidea*, 27.2°C in *Lampsilis abrupta*, and 30.3°C in *Megalonaias nervosa* (Ganser et al., in press). A sediment temperature of 25°C was exceeded 37-64% of the time and 27°C was exceeded 10-26% of the time during summer at one site in the UMR (Fig. 5). During the summer of 2006, the UMR experienced exceptionally low flows and high water temperatures which resulted in 31 days with sediment temperatures >29°C, 16 days with temperatures >30°C and 8 days with temperatures >31°C downstream of a thermal discharge (Dunn, 2009). Thus, temperatures that cause chronic mortality to juveniles in

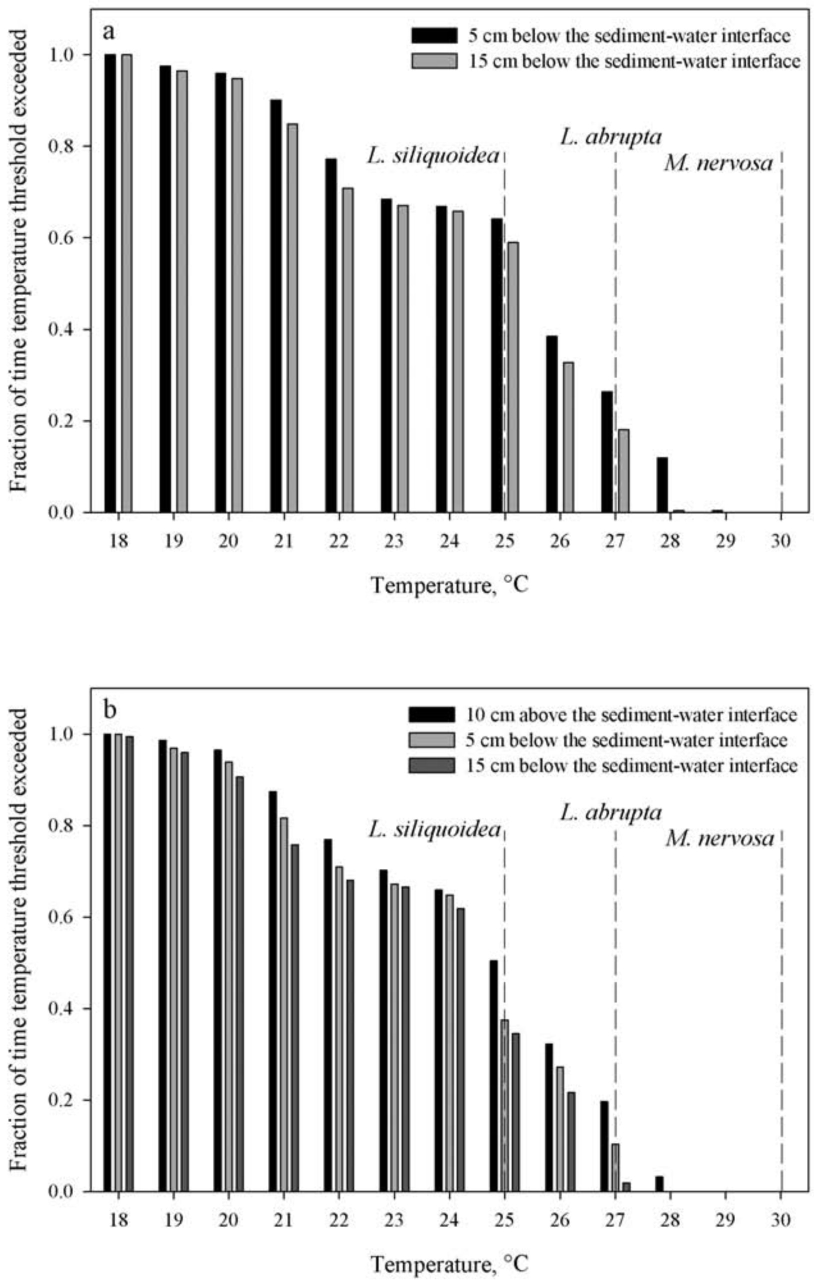

FIGURE 5

The fraction of time that a given river temperature was exceeded at Site 5 in the Upper Mississippi River. Dashed vertical lines represent the 28-day lethal temperature that resulted in 50% mortality in three mussel species (*Lampsilis siliquoidea*, *Lampsilis abrupta*, and *Megalonaias nervosa*) in laboratory studies (Ganser et al., in press). Temperatures were recorded every 3 hours during June, July and August 2011 at an upstream (a) and downstream (b) stake in this mussel bed.

laboratory studies can be exceeded for lengthy periods of time during summer in the UMR. Although most thermal tolerance data on juveniles are derived from water-only tests which may not accurately represent their benthic nature, a recent study showed that the addition of sediment allowing juveniles to burrow, did not offer any thermal protection in acute tests (Archambault et al., 2012).

We hypothesized that temperatures in surface waters might be more variable than in sediments (due to diel warming and cooling), although we have no evidence to support this. The lack of such an effect could result from our limited sample size or the fact that our surface water samples were taken from near the sediment-water interface. In a system as deep and well mixed as the UMR, our surface water temperatures may be more representative of sediment temperatures. Regardless, we observed considerable heterogeneity in surface water temperatures across all depth strata. This variation suggests that mussels may not need to move far to reach different temperatures. This might be especially important in juveniles — a life stage that spends much of their first few years buried in river sediments (Cope et al., 2008) and for which we know little about movement patterns. Such heterogeneity may create thermal refugia and mitigate some of the potential negative effects of temperature on mussels (Verbrugge et al., 2012).

Despite its limitations, this study increases our understanding of the potential effects of elevated river temperatures on native mussel assemblages and on the potential for sediments to provide a thermal buffer in rivers. Data on the thermal biology of native mussels are needed to help conserve and restore native mussel populations and to forecast species responses to climate change over the next few decades. Management actions such as the creation of thermal buffers in riparian zones and maintenance of sufficient flows during critical life history periods might reduce the effects of elevated temperatures on native mussel assemblages.

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OUR PURPOSE

The Freshwater Mollusk Conservation Society (FMCS) is dedicated to the conservation of and advocacy of freshwater mollusks, North America's most imperiled animals. Membership in the society is open to anyone interested in freshwater mollusks who supports the stated purposes of the Society which are as follows:

1) Advocate conservation of freshwater molluscan resources;

2) Serve as a conduit for information about freshwater mollusks;

3) Promote science-based management of freshwater mollusks;

4) Promote and facilitate education and awareness about freshwater mollusks and their function in freshwater ecosystems;

5) Assist with the facilitation of the National Strategy for the Conservation of Native Freshwater Mussels (Journal of Shellfish Research, 1999, Volume 17, Number 5), and a similar strategy under development for freshwater gastropods.

OUR HISTORY

The FMCS traces it's origins to 1992 when a symposium sponsored by the Upper Mississippi River Conservation Committee, USFWS, Mussel Mitigation Trust, and Tennessee Shell Company brought concerned people to St. Louis, Missouri to discuss the status, conservation, and management of freshwater mussels. This meeting resulted in the formation of a working group to develop the National Strategy for the Conservation of Native Freshwater Mussels and set the ground work for another freshwater mussel symposium. In 1995, the next symposium was also held in St. Louis, and both the 1992 and 1995 symposia had published proceedings. Then in March 1996, the Mississippi Interstate Cooperative Research Association (MICRA) formed a mussel committee. It was this committee (National Native Mussel Conservation Committee) whose function it was to implement the National Strategy for the Conservation of Native Freshwater Mussels by organizing a group of state, federal, and academic biologists, along with individuals from the commercial mussel industry. In March 1998, the NNMCC and attendees of the Conservation, Captive Care and Propagation of Freshwater Mussels Symposium held in Columbus, OH, voted to form the Freshwater Mollusk Conservation Society. In November 1998, the executive board drafted a society constitution and voted to incorporate the FMCS as a not-for-profit society. In March 1999, the FMCS held it's first symposium "Musseling in on Biodiversity" in Chattanooga, Tennessee. The symposium attracted 280 attendees; proceedings from that meeting are available for purchase. The second symposium was held in March 2001 in Pittsburgh, Pennsylvania, the third in March 2003 in Raleigh, North Carolina, the fourth in St. Paul, Minnesota in May 2005, the fifth in Little Rock, Arkansas in March 2007, the sixth in Baltimore, Maryland in April 2009, the seventh in Louisville, Kentucky in 2011, and the eighth in Guntersville, Alabama in 2013. The society also holds workshops on alternating years, and produces a newsletter four times a year.

FMCS SOCIETY COMMITTEES

Participation in any of the standing committees is open to any FMCS member. Committees include:

- Awards
- Environmental Quality and Affairs
- Gastropod Distribution and Status
- Genetics
- Guidelines and Techniques
- Information Exchange - Walkerana and Ellipsaria
- Mussel Distribution and Status
- Outreach
- Propagation and Restoration

TO JOIN FMCS OR SUBMIT A PAPER

Please visit our website for more information at http://www.molluskconservation.org

Or contact any of our board members or editors of WALKERANA to talk to someone of your needs. You'll find contact information on the back cover of this publication.