SRP13623

INVITED COMMENTARY

HP TODAY

HYDROLOGICAL PROCESSES
Hydrol. Process. **17**, 497–499 (2003)
Published online in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/hyp.5091

Stream temperature: scaling of observations and issues for modelling

Sherri L. Johnson*

Research Ecologist, Pacific Northwest Research Station, USFS, Corvallis, OR 97331, USA

*Correspondence to:
Sherri L. Johnson, Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331, USA.
E-mail: sherrijohnson@fs.fed.us

Stream temperature dynamics, which influence most in-stream biological processes, have been the focus of much controversy. Stream temperatures have become a major issue in some regions and the centre of policy debate, because elevated temperatures can negatively impact cold-water fish species, such as threatened or endangered salmonids. To add to the controversy, numerous contradictions exist in published literature about the controlling factors of stream temperature: the role of air temperature (Sullivan and Adams, 1990; Webb and Nobilis, 1997); effects of shade (Larson and Larson, 1996; Beschta, 1997); substrate fluxes and conduction (Brown, 1969; Webb and Zhang, 1997); and changes in longitudinal temperature trajectories downstream of harvested areas (Beschta *et al.*, 1987; Zwieniecki and Newton, 1999). Although the influences of stream temperature appear to be simple, we have much to learn about these complex processes. This commentary addresses two main points regarding modelling of stream temperature dynamics: the problems with air temperature correlations to predict stream temperature and the importance of scaling of factors, both microclimatic influences as well as reach-scale upstream influences.

An important distinction in understanding the influences of stream temperature is the differences between correlation and causation. For example, high correlations exist between air and stream temperature in the diurnal and seasonal patterns of temperature fluctuations; air temperature is occasionally used as a 'surrogate' for predictions instead of complex heat flux equations (Webb, 1987). Unfortunately, the literature has numerous examples of statements that air temperature is a major driver of stream temperature (Smith and Lavis, 1975; Sullivan and Adams, 1990), which can be confusing to readers unfamiliar with stream temperature dynamics. Heat budget analyses show that convection, or the transfer of heat energy from warmer air to cooler stream water is, in fact, only a small portion of the energy exchanges influencing stream temperature (Sinokrot and Stefan, 1993; Webb and Nobilis, 1997). The major factor influencing both air and stream temperature is incoming solar radiation. Correlations can be helpful in predicting patterns for a future time or a nearby location, but correlations do not imply causation.

Complex environmental gradients occur over very short distances away from the stream. Wind speed, relative humidity, subsurface saturation and soil and air temperature are very responsive to

This article is a US Government work and is in the public domain in the USA.

Received 30 October 2002
Accepted 30 October 2002

variations in landscape features and riparian vegetation distribution (Chen *et al.*, 1993). Measurement of these parameters close to the stream reveals very different conditions than if measured several metres away; and with increasing distance from the stream, more and more differences can occur. However, data from the nearest climatic station, which is often kilometres away from the study stream, is often used to represent environmental conditions for modelling. The non-site-specific data can provide general information about large-scale climatic trends, but are not accurate inputs for sensitive models. For example, the temperature gradient within substrates, especially within bedrock, can be problematic to measure accurately. Misrepresentation or exclusion of the potentially important process of conduction often results when subsurface temperatures or substrate types are estimated. Multiple fluxes can be occurring between water and substrates (Webb and Zhang, 1997): diurnal warming of a thin boundary layer at the interface between the rock and the water can be occurring during full sun, while seasonal temperature fluctuations at depth can be lagging those of the surface by months. Early research suggested that, for alluvial substrates, conduction was not an important heat flux (Brown, 1969; Beschta *et al.*, 1987), but more recent research suggests that hyporheic flows can dampen temperature extremes (Evans and Petts, 1997; Johnson, in preparation). Accurate representation of conditions within microclimates or across environmental gradients is critical for examining the sensitivity of a model to various processes.

Owing to the flowing nature of streams, stream temperature at a point is controlled not only by immediate surroundings, but also by upstream conditions. Determining the extent of the upstream zone of influence for stream temperature is a logistical challenge because travel time of water through reach is not a homogeneous process. More research is needed to examine under what conditions the stream temperature along the length of a river is influenced by fine-scale point processes versus upstream landscape-scale environmental conditions (Beschta *et al.*, 1987; Torgerson *et al.*, 1999; Zwieniecki and Newton, 1999). Characterizing the hydraulic retention time of water through a reach, and, therefore, the contact time during which energy exchanges can occur, requires understanding of potentially very complex surface and subsurface flow paths (Poole and Berman, 2001). Calculation of retention time of the water within a reach varies by the method of measurement and by the type of substrate (Johnson, in preparation). The source of water and the length of time it has been in contact with subsurface environments can be important factors influencing its temperature. Although some studies have referred to pulses of warm water moving through a stream network (Smith and Lavis, 1975; Beschta *et al.*, 1987), more recent research has noted that the time of daily temperature maxima is more synchronous than previously thought (Torgerson *et al.*, 1999). Site-specific local and climatic drivers may dominate for some metrics, such as time of maxima, whereas other metrics, such as minima or mean, might be more influenced by reach- or landscape-scale drivers.

Much remains to be learned about stream temperature dynamics and influences. The advent of a new technology over the past several years, of small, inexpensive temperature sensors coupled with data loggers, has allowed examination of spatial dynamics of stream temperature at higher resolution than possible before. Increased variability has been observed, which has led to a re-examination of our assumptions of temperature influences. Continued exploration of subsurface and surface microclimatic gradients with these inexpensive sensors will help in clarifying the magnitude and direction of energy fluxes influencing stream temperature. Although most efforts are focused on understanding the drivers of maximum stream temperatures, the study of minima might result in additional insights to the processes controlling stream temperature.

Research on stream temperature would benefit from critical evaluation of the mechanisms contributing to heat budgets. Although correlational models have limited transferability, the process-based stream temperature models can be useful in examining potential restoration or historical scenarios, assuming that the models are accurately depicting the dominant mechanisms at appropriate time steps. More research is needed on the effects of turbulence of water on evaporative fluxes and energy absorption, the influences of substrate type,

hydraulic retention time and stream flow paths on conduction, and the relevant upstream zone of parameterization as influenced by reach-scale hydraulic retention. Continued research will help to fill gaps and clarify assumptions in our present understanding of stream temperature dynamics.

References

Beschta RL. 1997. Riparian shade and stream temperature: an alternative perspective. *Rangelands* 19: 25–28.

Beschta RL, Bilby RE, Brown GW, Holtby LB, Hofstra TD. 1987. Stream temperature and aquatic habitat: fisheries and forestry interactions. In *Streamside Management: Forestry and Fishery Interactions*, Salo EO, Cundy TW (eds). Institute of Forest Resources, University of Washington: Seattle, WA; 191–232.

Brown GW. 1969. Predicting temperatures of small streams. *Water Resources Research* 5: 68–75.

Chen J, Franklin JF, Spies TA. 1993. Contrasting microclimates among clearcut, edge, and interior of old-growth Douglas-fir forest. *Agricultural and Forest Meteorology* 63: 219–237.

Evans EC, Petts GE. 1997. Hyporheic temperature patterns within riffles. *Hydrological Sciences Journal* 42: 199–213.

Larson LL, Larson SL. 1996. Riparian shade and stream temperature: a perspective. *Rangelands* 18: 149–152.

Poole GC, Berman CH. 2001. An ecological perspective on in-stream temperature: natural heat dynamics and mechanisms of human-caused thermal degradation. *Environmental Management* 27: 787–802.

Sinokrot BA, Stefan HG. 1993. Stream temperature dynamics: measurements and modelling. *Water Resources Research* 29: 2299–2312.

Smith K, Lavis ME. 1975. Environmental influences on the temperature of a small upland stream. *Oikos* 26: 228–236.

Sullivan K, Adams TA. 1990. *The physics of stream heating: an analysis of temperature patterns in stream environments based on physical principles and field data*. Weyerheauser Technical Report. 044–5002·90/2. Technology Center, Tacoma, WA 98477.

Torgerson CE, Price DM, Li HW, McIntosh BA. 1999. Multi-scale thermal refugia and stream habitat associations of Chinook salmon in northeastern Oregon. *Ecological Applications* 9: 301–319.

Webb BW. 1987. The relationship between air and water temperatures for a Devon River. *Report of the Transactions of the Devonion Association for the Advancement of Science* 119: 197–222.

Webb BW, Nobilis F. 1997. A long-term perspective on the nature of the air–water relationship: a case study. *Hydrological Processes* 11: 137–147.

Webb BW, Zhang Y. 1997. Spatial and seasonal variability in the components of the river heat budget. *Hydrological Processes* 11: 79–101.

Zwieniecki M, Newton. M. 1999. Influence of streamside cover and stream features on temperature trends in forested streams of Western Oregon. *Western Journal of Applied Forestry* 14: 106–112.