Notes

A Simple Method for In Situ Monitoring of Water Temperature in Substrates Used by Spawning Salmonids

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Abstract

Interstitial water temperature within spawning habitats of salmonids may differ from surface-water temperature depending on intragravel flow paths, geomorphic setting, or presence of groundwater. Because survival and developmental timing of salmon are partly controlled by temperature, monitoring temperature within gravels used by spawning salmonids is required to adequately describe the environment experienced by incubating eggs and embryos. Here we describe a simple method of deploying electronic data loggers within gravel substrates with minimal alteration of the natural gravel structure and composition. Using data collected in spawning sites used by summer and fall chum salmon Oncorhynchus keta from two streams within the Yukon River watershed, we compare contrasting thermal regimes to demonstrate the utility of this method.

Keywords: salmon; spawning; temperature; trout

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Introduction

Water temperature is a critical variable that controls the development and survival of salmonid embryos and alevins (Crisp 1988, 1990), and duration of incubation is related positively to water temperature within a range of suitable temperatures (Combs 1965; Brannon 1987; Murray and Beacham 1987; Crisp 1988; Murray and McPhail 1988). As described by Malcolm et al. (2008), in natural settings, temperature and its complex interactions with dissolved oxygen concentration are critical controls of developmental timing and survival. Although many salmonids select sites that maximize down-welling of cool oxygen-rich surface waters through the redd (Chapman 1988), some salmonids select sites characterized by upwelling groundwater or hyporheic water (Leman 1993; Baxter and Hauer 2000; Malcolm et al. 2002). Groundwater and hyporheic water can be very different from surface water in dissolved oxygen, temperature, and conductivity (Stanford and Ward 1988; Baxter and Hauer 2000; Edwards 2001), and these variables can vary greatly over relatively small spatial scales (White et al. 1987; Evans et al. 1995; Geist et al. 2002). Because of these complexities, surface-water temperatures may not describe the interstitial waters adequately, and monitoring of temperature within the substrates used by spawning salmonids is required to describe the thermal environment experienced by incubating eggs and embryos (Shepherd et al. 1986).

Sampling and monitoring of the properties of water within the substrate or hyporheic zones of streams and rivers is usually conducted using wells, piezometers, or by burying electronic data loggers (Dahm et al. 2006; Groves et al. 2008). Typically, in studies using wells or mini-piezometers, temperature is measured at a single point in time or periodically (e.g., Hansen 1975; Curry et al. 1995; Garrett et al. 1996; Alexander and Caissie 2003) or by use of continuously recording electronic data loggers within piezometers (Hanrahan 2007). Baxter and McPhail (1999) and Groves et al. (2008) planted eggs and temperature data loggers in artificial redds dug by hand to compare temperature with survival of planted eggs. Acornley (1999) and Malcolm et al. (2002) buried...
temperature data loggers in the substrate adjacent to redds and in nonspawning locations to collect continuous records of interstitial water temperature. The temporal frequency, periodicity of temperature sampling, and tools used to measure temperature will vary with study purpose. In any case, however, because the natural structure of the substrate may influence water flow (both velocity and direction), retention, and interaction between interstitial and surface waters (Carling et al. 2006), it is critical that methods to monitor water parameters disturb the natural substrate structure as little as possible (Barnard and McBain 1994, Supplemental Material, Reference S1, http://dx.doi.org/10.3996/032012-JFWM-025.S1). We describe a method of monitoring interstitial and hyporheic water temperatures by using temperature data loggers, which minimizes impacts to substrate structure and maximizes retention of data loggers in substrates used by spawning salmonids. This method uses an electronic temperature data logger attached to a plastic flag, and a driver that allows for placement of the data logger at a selected depth within the substrate. Our purpose here is to describe the method and present example data from two contrasting thermal habitats used by seasonal ecotypes (summer and fall spawners) of chum salmon Oncorhynchus keta from two tributaries of the Yukon River, Alaska.

Materials and Methods

Construction and installation of intergravel temperature loggers

Electronic data loggers capable of monitoring water temperatures at preassigned intervals are attached to a plastic zip-tie (Figure 1). To withstand pressures associated with burying and retrieving the data logger within gravel substrates, we use loggers that are entirely encased in plastic with no seams or openings. The data logger is attached to one end of a plastic zip-tie with stainless-steel aircraft safety wire threaded through a small hole (Figure 1). The desired depth of deployment determines the length of the zip-tie and placement of the data logger. To monitor water temperatures at the depth of the egg pocket, we use a depth of 35–40 cm based on our experience excavating redds of chum salmon. For other species, approximate egg-pocket depths are available from DeVries (1997). To simplify recovery of data loggers, we attach a surveyor’s brush-type flag to the top end of the zip-tie and a loop of nylon cord that remains at the surface of the gravel (Figure 1). After calibration of the temperature data logger, the desired sampling interval is determined based on the intended duration of deployment and memory size of the temperature data logger (Dunham et al. 2005, Supplemental Material, Reference S3, http://dx.doi.org/10.3996/032012-JFWM-025.S3). Using standard sampling intervals determined by the U.S. Geological Survey, we usually set a sampling interval of 15 min (Wilde 2006, Supplemental Material, Reference S4, http://dx.doi.org/10.3996/032012-JFWM-025.S4) so data are easily comparable with other data sources, but other intervals may be appropriate depending on daily variability and range of temperature (Dunham et al. 2005, Supplemental Material, Reference S3, http://dx.doi.org/10.3996/032012-JFWM-025.S3).

An aluminum pipe and steel probe (Figure 2), similar to that described by Baxter et al. (2003) for placement of
mini-piezometers, are used to place the temperature data logger in the substrate. The inside diameter of the pipe is sized to allow for passage of the prepared data logger (5 cm in our case), and the steel probe is designed to nest within the pipe so that the pointed tip protrudes out the end of the pipe. Channels in the probe’s tip are designed to minimize any suction, which might alter fine sediment or sand distribution when the steel probe is removed from the pipe (Figure 2). First, the nested probe and pipe are driven into the substrate to the intended depth of deployment with a fence-post driver or sledge hammer (Figure 3a). The steel probe is carefully and slowly removed from the pipe while the aluminum pipe is held in place (Figure 3b). The temperature data logger is then dropped into the pipe and a dowel is used to hold the data logger in place while the pipe is slowly lifted from the substrate (Figure 3c). The surveyor’s flag is left protruding above the substrate to identify the location of the data logger (Figure 3d). In addition, we mark the location using a survey-grade GPS and make multiple measures to easily identifiable landmarks to allow for identification of the site using triangulation. A paired temperature data logger is simultaneously deployed in the surface water adjacent to the intergravel data logger. See Dunham et al. (2005, Supplemental Material, Reference S3, http://dx.doi.org/10.3996/032012-JFWM-025.S3) for surface-water deployment methods. After installing the temperature data logger, water temperature (within an adjacent mini-piezometer or by using a probe-type thermistor) is measured to calibrate the data logger as installed. At regular periods, such measurements can be conducted to monitor drift in the electronic temperature data logger and maximize data quality. At the conclusion of the expected incubation period, based on published relations or after the observation of emerging fry, the temperature data logger is recovered from the substrate.

Comparison of thermal habitats used by seasonal ecotypes of chum salmon
To demonstrate use of this method, we deployed temperature data loggers in spawning areas used by summer chum salmon and fall chum salmon. Clear Creek (66°13′00″N, 156°29′43″W) is a tributary of the Hogatza River located in northwestern Alaska. Summer chum salmon are the seasonal ecotype at this location and generally migrate in June and July, spawn in July and August, and fry emergence and downstream migration occur between early May and early June (C. E. Zimmerman, unpublished data). In contrast, the Tanana River (64°41′21″N, 147°17′40″W), is used by spawning fall chum salmon that migrate and spawn in November, and their offspring emerge in April (Buril et al. 2010, Supplemental Material, Reference S2, http://dx.doi.org/10.3996/032012-JFWM-025.S2). At both sites, we installed temperature data loggers in areas used by spawning salmon (immediately adjacent to redds) using the methods described above. Data loggers were positioned immediately next to redds to avoid disturbing incubating eggs and they recorded temperature every 15 min. At Clear Creek, we installed over 50 data loggers in...
spawning substrates and, in the Tanana River, we installed 45 data loggers in spawning substrates. Data loggers were retrieved after emergent fry were observed. For each data logger, we calculated accumulated thermal units (ATU): the sum of daily mean temperature above 0°C corresponding to the time from fertilization to emergence from the gravel. We used observations of spawning salmon and emergent fry to determine the timing of fertilization and emergence, respectively.

**Results**

Water temperatures corresponding to the spawning and incubation period of chum salmon differed between the two sites examined (Figure 4). Interstitial water temperatures adjacent to summer chum salmon redd in Clear Creek were nearly identical to surface-water temperatures (Figure 4), with mean daily differences between interstitial and surface waters ranging from −2.7 to 2.2°C. Accumulated thermal units of interstitial water ranged from 351 to 476°C and ATU of surface water was 407°C. In contrast, interstitial water temperature adjacent to fall chum salmon redd in the Tanana River was stable (varying by < 2°C during the incubation period) and was warmer than surface waters (Figure 4). Mean daily difference between interstitial water and surface water ranged from 0.2 to 5.3°C and ATU differed between interstitial water (688–780°C) and surface water (158°C).

**Figure 3.** Steps for deploying electronic data loggers in spawning gravel: (a) pound nested steel probe and pipe to monitoring depth; (b) slowly remove steel probe from pipe; (c) drop temperature data logger into pipe and hold in place with dowel while pipe is gently removed from substrate; (d) temperature data logger deployed in substrate with surveyor marker extending above gravel surface.
Discussion

We have described a method of deploying date loggers to monitor temperature in spawning substrates used by salmon. To demonstrate the potential utility of this method, we presented data from two contrasting locations. The timing of spawning and thermal habitats used at Clear Creek and Tanana River differ and demonstrate the use of down-welling versus up-welling spawning sites, respectively. In spite of the differences in timing of spawning, chum salmon in the two sites studied generally emerge at the same time. This synchrony of emergence timing is presumed to have evolved in response to selection related to downstream migration and early marine mortality and productivity patterns (Hillgruber and Zimmerman 2009) and would require local adaptation to thermal regimes. Accumulated thermal units required to reach developmental stages vary among species and populations (Beacham and Murray 1986). For example, within a stream in Washington, early run chum salmon required 1060°C ATU to reach emergence, but late-run chum salmon emerged after 933°C ATU (Koski 1975).

We have used this method to deploy temperature data loggers at > 100 sites adjacent to redds constructed by chum salmon, coho salmon O. kisutch, and sockeye salmon O. nerka throughout Alaska. In most cases the loggers have remained in place for between 5 and 6 mo and, to date, we have been unable to relocate only 12 loggers. In most cases, this was due to aggradation or scouring of sediment or formation of anchor ice and overflow and it occurred in larger rivers, such as the Tanana River. In smaller streams and side-channels, loggers are subjected to less scour and fewer ice floes during spring break-up, which results in less chance of displacement or burial. We have, however, had one logger removed from a smaller stream by a passerby who, presumably thinking it was trash, removed it from the substrate. As a result, we now tag all loggers with a metal tag with contact information to encourage return of the logger. These metal tags are attached to the nylon cord and remain at the surface of the gravel.

We assume that this method of deployment does little to disturb the natural structure of the substrate and therefore provides a continuous temperature record that reflects unaltered temperatures representative of conditions at depths where salmonid eggs and embryos incubate. We routinely use a probe to collect point measures of temperature adjacent to locations where we deploy data loggers and have never observed any...
differences in temperature detected by the logger or the probe. Similarly, when deployed near mini-piezometers, such as those described by Baxter et al. (2003), data loggers register temperatures similar to those of water drawn from the mini-piezometer (presumably interstitial water). As a result, we are confident that loggers deployed using these methods are sampling interstitial waters representative of temperatures in incubating habitats used by salmonids.

One of the benefits of this method is its simplicity and ease of use. As described by Acornley (1999), the data loggers used here are similar to those commonly used by fishery biologists and ecologists and are relatively inexpensive (Dunham et al. 2005, Supplemental Material, Reference S3, http://dx.doi.org/10.3996/032012-JFWM-025.S3). In addition, modern, electronic data loggers are capable of accuracy and precision of within 1°C, which is critical when calculating ATU because small inaccuracies can result in substantial cumulative errors. The remaining materials are available from hardware stores. Unlike temperature data loggers such as those used by Malcolm et al. (2002) and Soulsby et al. (2009), the loggers we describe do not require a cable link between the sensor and a data-logging module, which is a distinct advantage when deploying loggers throughout habitats used by salmonids.

The role of groundwater and hyporheic water as important components of stream ecosystems has been readily recognized over the past 20 y (Stanford and Ward 1988; Boulton et al. 2010). Similarly, the role of thermal variability (relative to surface water) and use of groundwater or hyporheic seeps by spawning salmonids has received increased attention (e.g., Baxter and Hauer 2000; Geist et al. 2002, 2008; Malcolm et al. 2008). The role of groundwater and warmer hyporheic water is especially important in northern latitudes (Power et al. 1999). Further, research and understanding of the role of thermal heterogeneity among spawning sites used by salmonids is critical if we are to understand the role of climate variability in driving the distribution and performance of salmon in northern latitudes. We hope the method we describe here will provide a simple and accurate means to investigate thermal controls of salmon spawning and incubation.

Supplemental Material

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