NOTES

Relationships Between Stream and Intragravel Temperatures in Coastal Drainages, and Some Implications for Fisheries Workers

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By a depth of 10 cm into the streambed, water temperatures are likely to be different from those in the open water of the stream. Combined results from three independent studies on disparate streams on the Pacific Northwest coast indicated that there are widespread similarities in the thermal behavior of intragravel water. In general, the thermal mass of the substrate causes parallel but lagged and buffered heating and cooling trends in infiltration-source intragravel water compared with surface water. Intragravel mean daily temperatures were generally 0.5–1.0°C warmer in winter and 0.5–1.5°C cooler in summer, with cross-overs around March and October; intragravel daily maximum temperatures could be up to 6°C different in summer (a difference of 4°C was common). The degree of difference showed considerable site-specific variation, and potentially can be affected by several factors. Such intragravel temperature differences have implications for those involved in salmonid egg incubation and fry emergence studies, enhancement projects, benthic invertebrate research, and environmental impact assessments.

La température de l'eau se trouvant à 10 cm sous la surface du lit d'un cours d'eau tend à être différente de celle de l'eau du cours d'eau lui-même. Les résultats de trois études indépendantes portant sur trois cours d'eau distincts de la côte nord-ouest du Pacifique ont montré l'existence de similitudes généralisées quant au comportement thermique de l'eau occupant les interstices du gravier. De façon générale, la masse thermique du substrat provoque des réchauffements ou des refroidissements, décalés et amoindris, de l'eau intersticielle d'infiltration comparativement à l'eau de surface. La température moyenne quotidienne dans le gravier était généralement de 0,5 à 1,0°C plus chaude en hiver et de 0,5 à 1,5°C plus froide en été, les inversions se produisant vers mars et octobre. La température maximale quotidienne dans le gravier pouvait différer de 6°C de la température des eaux de surface en été (une différence de 4°C était courante). L'écart variait de façon considérable en fonction du site et était sans doute fonction de plusieurs facteurs. Ces écarts de température de l'eau présentent un grand intérêt pour les études de l'incubation des oeufs de salmonidés et de l'émergence des alevins, les projets de mise en valeur, les recherches sur les invertébrés benthiques et les évaluations d'incidences environnementales.

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The purpose of this paper is to alert resource managers to the importance of determining the relationship between intragravel and surface water temperatures. Some examples of the consequences of not correcting for such a difference are discussed.

It often has been observed during field surveys that certain species of Pacific salmon, especially chum (*Oncorhynchus keta*), are attracted to groundwater-fed areas for spawning (Kogl 1965; ADFG 1985). The sensory basis of groundwater detection is not clear. However, the advantages of using such locations would include exposure of the eggs to cleaner water, more stable flows, and a better incubation temperature regime. With respect to the latter factor, several studies suggest that water temperature is a driving factor in determining the progress of incubation and emergence of Pacific salmon fry (e.g. Leitritz and Lewis 1976). Other workers have noted that

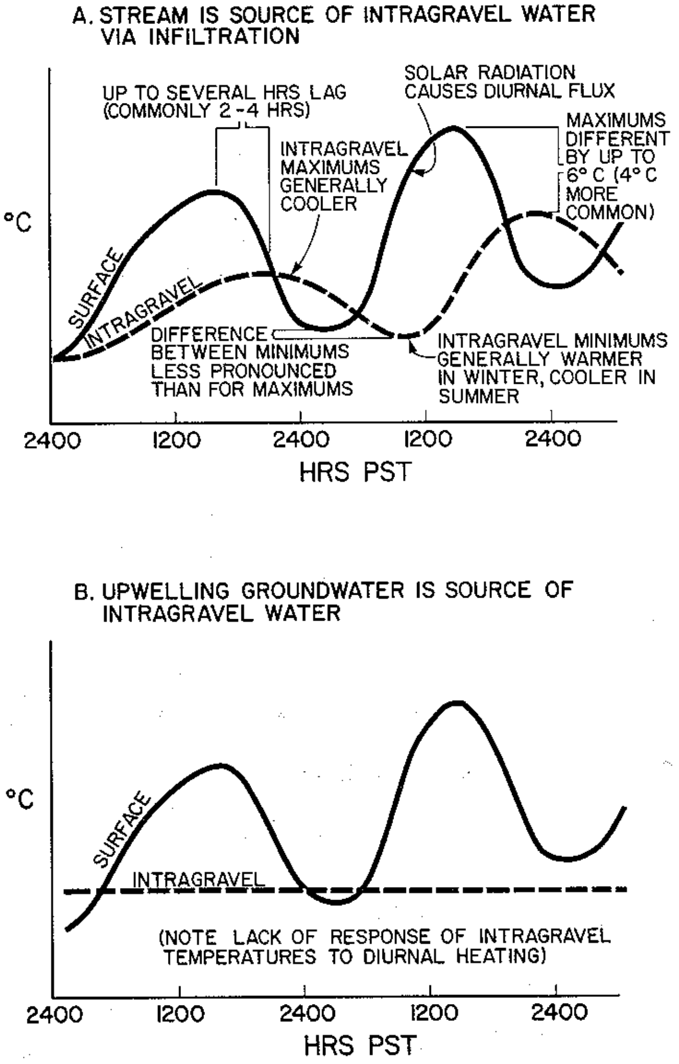

FIG. 1. General summer diurnal surface and intragravel water temperature patterns.

intragravel water temperatures can differ from surface water temperatures (e.g. Sheridan 1962). What has not been obvious until recently is how widespread intragravel temperature differences might be and how they might vary over time.

Each of the coauthors independently compared intragravel and surface water temperature regimes of coastal streams in the Pacific Northwest. The three studies were done with different objectives in mind, using differing methodologies, and were widely separated geographically. Nevertheless, the combined results balance the strengths and weaknesses of the individual studies and allow a more general overview of the behavior of intragravel water temperatures.

Materials and Methods

The reader is referred to the individual reports (Hartman and Leahy 1983, for Carnation Creek; Shepherd 1984, for Glendale Creek; and Wilson et al. 1980, for the Terror and Kizhuyak rivers) for full details on the methods and results of the three studies. The following sections highlight the different approaches of each study.

Carnation Creek — This system flows into Barkley Sound on the west coast of Vancouver Island, British Columbia. This small (~10 km^2) watershed has been the subject of a 15-yr multidisciplinary study on the effects of logging (see Hartman 1982 for a recent review of results). Since 1970, monthly discharges have ranged 0.03−63 m^3·s^{-1}. Surface water temperatures have ranged 1.5−17.0°C seasonally. Intragravel and surface temperatures were measured with a calibration thermometer or with a Fenwell Electronics 1000 OHM thermistor probe coupled to a Beckman voltmeter and calibrated to the thermometer (accuracy ± 0.1°C). For each intragravel measurement, a 2.5-cm pipe 90 cm long was fitted around a pointed steel core and both were driven 10−30 cm into the streambed. The lower 8−10 cm of the pipe was perforated to allow entry of intragravel water when the driving rod was removed. Throughout 1981−82, 20 series of intragravel and stream temperatures were recorded. Each series consisted of paired readings at a minimum of 10 sites. It is emphasized that these were instantaneous samples; measurement of diel variations was not done, beyond comparison of "morning" and "afternoon" results.

Glendale Creek — This lake-headed system flows into Knight Inlet, located on the central coast of British Columbia. Water temperature studies were done between 1981 and 1983 as part of a program determining the feasibility of constructing a spawning channel for pink salmon (*Oncorhynchus gorbuscha*). Glendale Creek drains a total of 136 km^2; average monthly flows have ranged 4−11 m^3·s^{-1} since 1971. Surface water temperature ranged 2−19°C over the 1983 study period. Intragravel and surface temperatures were measured in two ways. During February, April, and May of 1983, point sampling was done using a calibrated YSI model 43TD thermistor (accuracy ± 0.5°C) and a heavy pointed steel pipe (3 mm wall thickness, 25 mm ID, and 120 cm long) perforated over the lower 12 cm. The pipe was driven to a depth of 30 cm and the temperature immediately measured at the bottom of the pipe. From one to five sites were sampled within each of five cross-sections. Also, two Peabody−Ryan J-90 submersible thermographs were calibrated and installed at a site having a representative temperature difference during the January survey. One thermograph was buried at about 30 cm depth, and the other was cabled to the bottom nearby. Although these machines were maintained through to November of 1983, malfunctions resulted in loss of intragravel data for the first half of May and most of November and surface data for the last half of August through the first half of September of that year. No data were collected for the months of December and January.

Terror and Kizhuyak rivers — These two systems are located on Kodiak Island, Alaska. Temperature studies were undertaken as part of an environmental assessment of a proposed hydroelectric project which would divert Terror River water via a reservoir and tunnel into the Kizhuyak River. The Kizhuyak and Terror watersheds are 141 and 126 km^2, respectively; average monthly flows have ranged 1.1−17 and 1.4−23 m^3·s^{-1}. Surface water temperatures ranged 1−12.5°C during the 1980 study period. Three sites in the Kizhuyak and two in the Terror were selected on the basis of egg or alevin presence. Three armored temperature probes were installed at each site: at the streambed surface, at 10−25 cm depth, and at 25−50 cm depth. Each probe was attached to a YSI model 42SC telethermometer (accuracy ±0.2°C), which could be read directly or connected to a Linear model 142 strip chart recorder. Instantaneous measurements were taken between early April and late August, and at least one continuous 24-h cycle was recorded

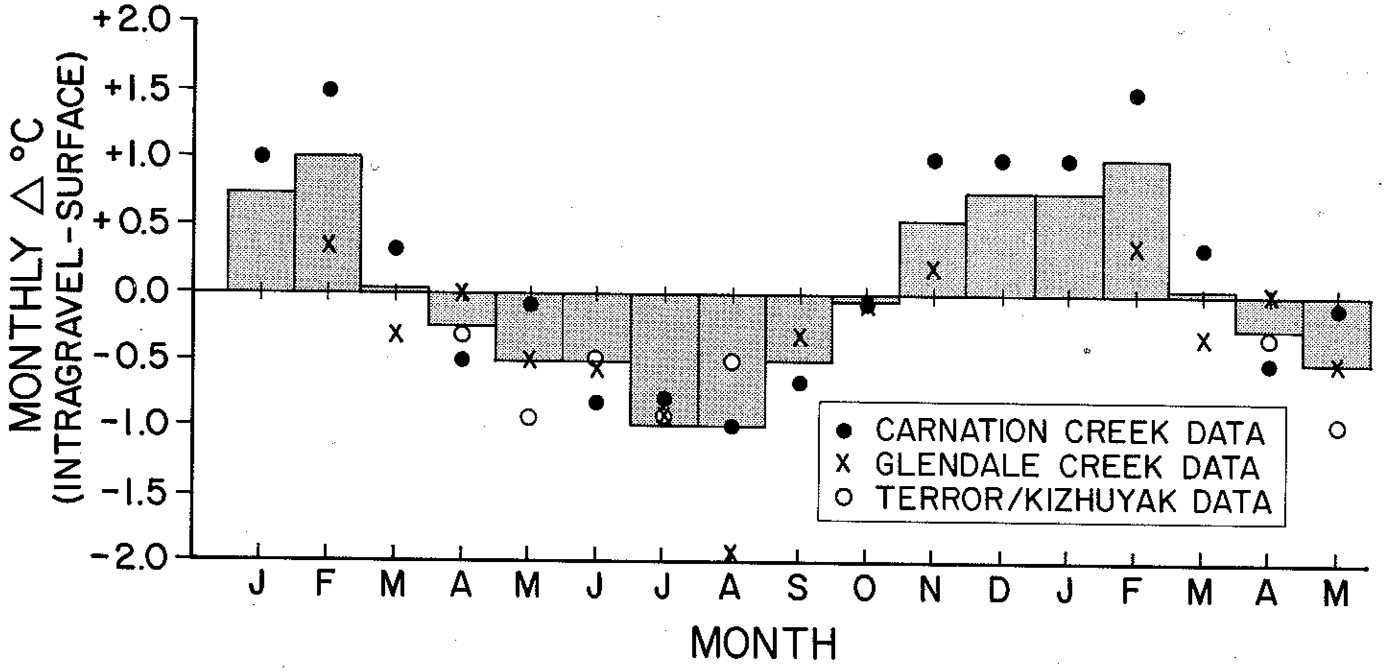

FIG. 2. Monthly differences between surface and intragravel water temperatures, presuming stream is the primary source of intragravel water. Actual average monthly differences from the three studies (points) were used to derive approximations (bars) by eye.

for all but one site in May, July, and August of 1980. This study provided the best diurnal data for the spring and summer period, when differences were greatest.

Results

The combined results of the three studies confirm that intragravel water temperatures can be expected to differ regularly from surface water temperatures. In general, one can expect intragravel water temperatures to be buffered by the thermal mass of the substrate. This buffering effect seems to be complete at a depth of 10 cm. Where intragravel flows are maintained primarily by infiltration of diurnally heated surface water into the substrate (which is seen as the common situation in the mainstem of larger streams), one can expect parallel, but lagged and buffered, heating/cooling trends in the intragravel versus the surface water (Fig. 1A).

A general predictive model of the differences in water temperatures that might be expected for infiltration-source intragravel water is shown in Fig. 2. The reader is cautioned not to derive precise monthly correction factors from this figure, as site-specific factors can result in considerable variation. One extreme example is shown in Fig. 1B, where the dominant source of intragravel water is upwelling groundwater. In this case, the intragravel temperature is highly buffered and will show little or no response to diurnal heating of the surface water. At such sites, intragravel temperatures will show only slow changes, on a seasonal rather than a diel scale. Such strong groundwater influence will tend to increase the amplitude of the curve shown in Fig. 2. For example, one section of Carnation Creek was heavily influenced by groundwater, and intragravel temperatures were as much as 3°C cooler in summer and over 5°C warmer in winter (Hartman and Leahy 1983).

Discussion

Several factors can affect the intragravel thermal regime. Hewlett and Fortson (1982) and Hartman et al. (1982) independently speculated that when groundwater is an important source of intragravel flows, logging of the areas where percolation from the surface occurs can increase groundwater temperatures by increasing solar heating effects. In winter, ice dams can develop on a river mainstem, forcing cold river water down side channels and sloughs normally fed solely by groundwater upwelling. Infiltration of 0°C water into these areas can dramatically alter the thermal regime and delay the development of, or even kill, incubating embryos (e.g. ADFG 1983). The degree of interchange between surface and intragravel water may depend on the stream's physical characteristics, including flow rate and turbulence, gradient, how even the streambed is, and the coarseness of the substrate (Pollard 1955; Vaux 1968; Sowden and Power 1985). In areas of tidal influence at Carnation Creek, diel intragravel temperatures appear to be warmer than surface temperatures in summer and colder in winter. This is the reverse of what is generally experienced in upstream areas, and probably is due to percolation of incoming water through beach and bank areas that have been exposed to the more extreme atmospheric heating or cooling during low tide.

There are many implications of the above phenomena for fisheries workers. Where intragravel temperatures differ, the use of surface temperatures in accumulated thermal unit (ATU, degrees Celsius) calculations of hatch and emergence timings will throw such predictions off. This could lead the life history researcher to incorrectly hypothesize stock-specific biological adaptations or additional physical factors such as temperature "triggers," stage of freshet, or phase of moon, where none in fact actually exist. In the construction of artificial spawning channels, a lack of recognition of this potential for different thermal regimes could result in actual fry emergence timings that are significantly skewed from the desired situation. Before committing to the site, one should consider the degree of groundwater contribution, both at natural spawning areas and at the proposed channel site.

In both field studies and the operation of spawning channels,

TABLE 1. Calculated ATU values to emergence for 1984 brood sockeye in Fulton Spawning Channel 2.

	ATU (surface temp.)	Difference	ATU (intragravel temp.)[a]	Difference
50% spawning to 50% emergence dates[b]	793	−44	890	+2
MAWW[c]	837		888	

[a] Adjusted using values shown in Fig. 2 (there is no groundwater input to Channel 2).

[b] Taken from spawner counts and fry trapping data.

[c] MAWW = maximum alevin wet weight; calculated per Belehradec model (Alderdice and Velsen 1978) using parameter values recently developed for sockeye (F. Velsen, J. Jensen, and D. Alderdice, unpubl. data).

the planning and coverage of fry counts might be improved if fry migrations were predicted using intragravel temperatures. Taking the Fulton sockeye (*Oncorhynchus nerka*) Spawning Channel 2 on Babine Lake, British Columbia, as an example, the 1984–85 interval between the 50% spawning and 50% emergence dates worked out to 793 ATU using surface temperature data, but was 97 ATU higher when the surface temperatures were adjusted to reflect intragravel conditions (Table 1). Maximum alevin wet weight (MAWW) and thus emergence were predicted to occur 9 d later than actual fry emigration data would have suggested (emergence has been related to attainment of MAWW by Heming 1982). When surface temperatures were corrected to reflect the intragravel situation, MAWW and emergence were predicted to occur on the same day as the actual date of migration. Although such accuracy is perhaps fortuitous given the many assumptions used in the calculation sequence, it does demonstrate the potential for improving the precision with which incubation timings can be predicted.

Where workers are planting eggs into streams, variations in intragravel temperatures along the stream's length should be considered. "Hotspots" could be used or avoided for egg planting, depending on the species and purpose. For instance, coho (*Oncorhynchus kisutch*) that emerge early tend to achieve a larger size by fall, although this advantage might be offset by their higher probability of experiencing freshets and being flushed seaward (Scrivener and Andersen 1984); species such as pink, chum, and sockeye can be quite sensitive to premature emergence in that prey levels could be low enough to cause mortality through starvation (Bilton and Robins 1973). For the researcher examining distributional behavior of benthos, vertical and horizontal variations in intragravel temperatures may be an important environmental influence.

Intragravel water temperatures can be modified by other activities in the watershed. A prime example is changes in water temperatures with logging. It may be possible for management workers to map areas of groundwater influence and to plan clearcuts either to take advantage of heated input water or to ensure maintenance of cool water input to the groundwater aquifer. Furthermore, it is possible that where large river diversion projects result in high spring–summer flows being diverted or stored, recharges to the downstream water table may be reduced. Such reduction could result in lower groundwater outflows into side channels on the downstream flood plain during the winter period and subsequent adverse effects on salmon spawning and incubation success. Even if flow reduction did not occur, there may be a relationship between reservoir release temperatures and downstream intragravel temperatures which would be important to examine.

We believe that the role of groundwater, and the diversity between stream and intragravel temperatures, should be considered carefully by those involved in fish enhancement and habitat management projects. These phenomena certainly deserve further investigation, particularly in areas subject to greater climatic extremes (i.e. where water temperatures fall below 1°C or exceed 19°C). Some very useful information on the complexities and significance of groundwater influences could result from cooperative research done by groundwater hydrologists and fisheries biologists. A related area worth further study is that of intragravel dissolved gases. Groundwater often is supersaturated in nitrogen and undersaturated in oxygen. Spawning success may be questionable in some cases; certainly, low oxygen levels are known to slow development (Doudoroff and Shumway 1970; Davis 1975) and could affect the precision of ATU predictions.

In summary, our studies show clearly that the fisheries worker cannot assume that stream temperatures are identical to those experienced by the egg in the intragravel environment.

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