

Science

FINDINGS

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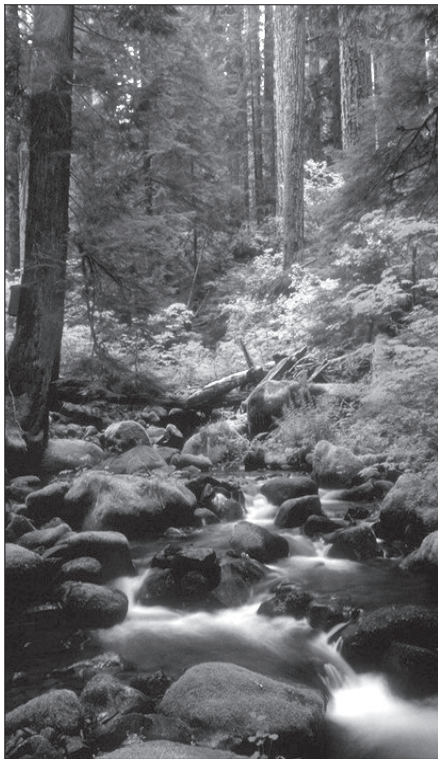
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“Science affects the way we think together.”

Lewis Thomas

KEEPING IT COOL: UNRAVELING THE INFLUENCES ON STREAM TEMPERATURE



Water temperature in Pacific Northwest mountain streams regulates virtually every biotic component of the aquatic ecosystem.

In the slanting sun of late afternoon the shadows of great branches reached across the river, and the trees took the river in their arms.

—Norman Maclean

It would be difficult to overstate the importance of water temperature in regulating stream ecosystems. Temperature sets the pace of nearly every

living organism—from caddisflies to the bacteria that cycle essential nutrients. Most notably, water temperature affects fish. In Pacific Northwest streams, where salmon and trout reign supreme, the proper temperature is cold, very cold.

Fish are exothermic, or cold-blooded. The temperature of the water surrounding them acts as a throttle on their metabolism. From the very start, temperature controls how fast salmon eggs mature and the timing of emergence of larval salmon from the nursery gravels of the streambed. And at the end of their lives, when adult spring Chinook salmon return to their natal streams, temperature will control how fast they burn reserves of body fat and if they survive the warm summer months to spawn in the fall. Moreover, several diseases that infect fish are kept in check by cold water. When temperatures rise, all these adaptations are thrown off, and fish populations—some of which are already imperiled—are put at higher risk. Given this, it is not surprising that scientists and land managers are so concerned with rising stream temperatures throughout the Pacific Northwest.

“Stream temperature dynamics have been the focus of much controversy and have been at the center of a long-standing policy debate,” says Sherri Johnson, a research ecologist at the PNW Research Station in Corvallis, Oregon. “To add to the controversy, numerous contradictions exist in the published literature about the controlling factors of stream temperature, such as the role of air temperature, shade, substrate, and timber harvest.”

When Johnson joined the station she inadvertently entered a debate over the controls

IN SUMMARY

Water temperature influences virtually every biotic component of stream ecosystems. Not surprisingly, increased summer temperatures in streams with coldwater species of fish such as salmon and trout have become a topic of concern regionally and internationally. Although stream temperature has been studied for many years, controversy continues over the relative influences of shade, air temperature, and substrate on temperature dynamics.

Researchers at the PNW Station have recently conducted experiments and calculated heat budgets that itemize the relative influence of several factors on the water temperature of mountain streams in western Oregon. New technologies allow more detailed measurements of heat fluxes and more accurate determination of the factors affecting stream temperature, allowing management practices to be tailored to minimize their influence on stream ecosystems.

Direct solar radiation is the primary contributor to daily fluctuations in water temperature. Managing for shade by maintaining streamside vegetation is an effective way to reduce heat flux. In addition, the type of substrate and the length of time that stream water spends below the stream channel is an important predictor of daily temperature variations. Much remains to be learned about how these factors vary across the landscape.

on stream temperature. “Although it might seem like a ‘no-brainer,’ people were still arguing over the importance of shade associated with streamside vegetation on water temperature,” says Johnson. “I was able to conduct an experiment that can hopefully put that question to rest.”

Johnson’s experiment involved a profusion of black plastic and more than a mile of parachute cord. But more on that later.

Shade is just one factor—albeit an important one—in the debate on how to keep streams cold. Other factors, which have only recently gained attention, are the composition of the streambed and length of time that water spends flowing through the substrate. The region of streamflow that is beneath and adjacent to the stream channel is termed the hyporheic zone; it is the unseen portion of nearly every stream with a porous substrate. Steve Wondzell is an expert in hyporheic zones and a research ecologist at the PNW Research Station in Olympia, Washington. He and Johnson have been working together to unravel the myriad influences on stream temperature.

CORRELATION AND CAUSATION

Interconnectedness is the essence of ecology. The complexity of natural systems makes it difficult to isolate one process from another. Therefore, when an ecologist devises an experiment that simply and accurately measures a single ecological process, it is termed elegant. And that is how Wondzell describes Johnson’s shading experiment, elegant.

Johnson credits her experience in boating with her ability to suspend 1,500 square yards of black plastic tarp 6 feet above a stream. “A recent flood had removed all the trees from the stream bank, so we had to experiment with ways to support and suspend the plastic; in the end we used more than a mile of parachute cord to keep it in place,” she says. “Once the tarp was up, it



More than 1,500 square yards of black plastic sheeting and more than a mile of parachute cord was used to shade a section of stream in the central Cascades Range, Oregon.

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KEY FINDINGS

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- Stream temperature has been studied for many years, yet until recently, there remained considerable uncertainty and controversy over the relative influence of shade, air temperature, and substrate in controlling stream temperatures. This research uses new technologies to make more accurate determination of the factors affecting stream temperature allowing management practices to be tailored to minimize their influence on stream ecosystems.

- The type of substrate can influence stream temperature dynamics. Bedrock reaches have wide daily summer stream temperature fluctuations, with high maxima and low minima. In contrast, stream reaches with gravel bottoms and belowground flows have a much narrower range of daily fluctuations.

- Air temperature was once thought to be a major factor influencing the water temperature in streams. A heat budget analysis, using data from streamside climate stations, showed that direct solar radiation, not air temperature, is the largest contributor to changes in daily temperature.

Purpose of PNW Science Findings

To provide scientific information to people who make and influence decisions about managing land.

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effectively shaded the stream without influencing the air flow directly above the water.”

The experiment was conducted on a small mountain stream in the western Cascades of Oregon within the H.J. Andrews Experimental Forest. Scientists have been collecting ecological data, including stream temperature data, in this particular watershed over several decades.

Johnson measured the water and air temperature at half-hour intervals around the clock in multiple places along the stream reach. Data was collected for 3 weeks before shading, 3 weeks during shading, and 3 weeks after shading. She also measured incoming solar radiation above and below the tarp.

“Although it might seem obvious that shade would affect the water temperature, there were many people who believed that shade had a minor role in the heat budget of a

stream,” says Johnson. “Air temperature was thought to be the major player.”

The debate over the role of air temperature in controlling stream temperature harkens back to a lesson you might have learned in an introductory statistics class: correlation does not imply causation. For many years, natural resource managers have been using predictive equations, based on air temperature, to estimate stream temperature. When air temperature goes up, stream temperature generally goes up—when air temperature goes down, stream temperature goes down. This has been an effective way to estimate stream temperature over broad areas. The use of these equations led people to assume that stream temperature was controlled by air temperature. However, just because air and stream temperatures are correlated does not mean that there is a cause-and-effect relationship.

Johnson’s shading experiment went a long way in resolving this debate. “The major factor influencing both stream and air temperature is incoming solar radiation,” she explains. “They are correlated because they are both responding to daily cycles of solar energy.”

Shading reduced the direct radiation to the stream water under the plastic, so it was cooler than the stream water in the sun, regardless of what happened to the air temperature. “The effect of the shade was seen primarily through decreases in the maximum daily water temperature,” says Johnson. “Interestingly, there was no significant difference in the average or minimum daily temperature.”

SHARING WARMTH

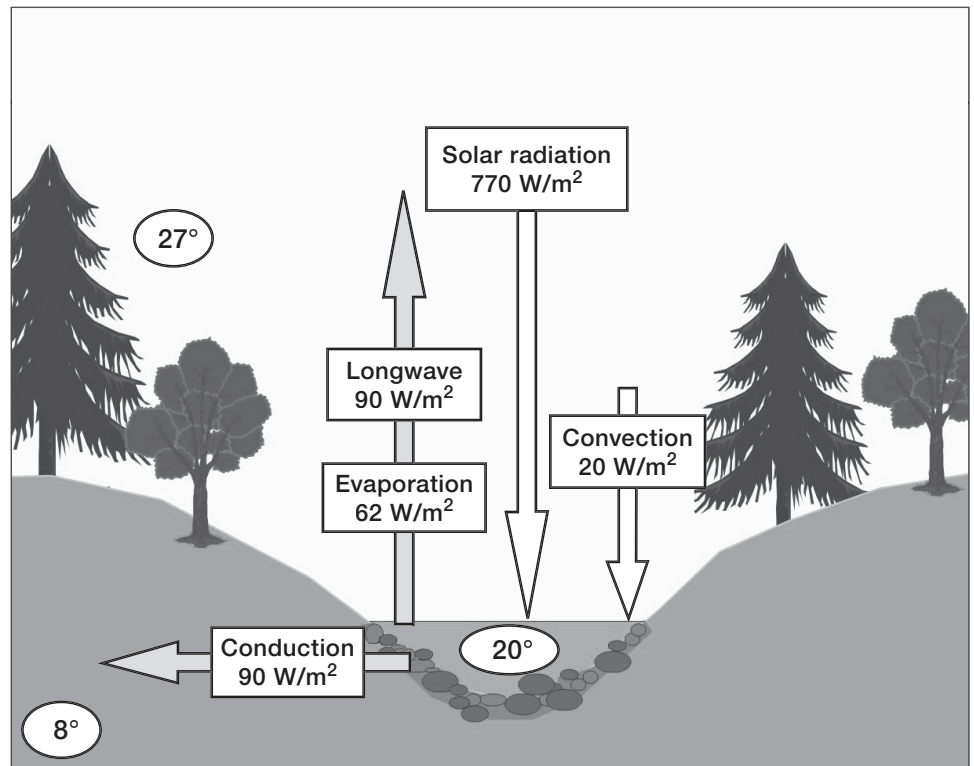
In addition to the shading experiment, Johnson and Wondzell have been investigating the function that the streambed plays in moderating water temperature. Similar to the role of shade, the role of substrate has been a topic where our understanding has evolved, and taken some wrong turns over time. As a result, this is another topic where there has been conflicting information in the scientific literature.

“There was an error based on an early experiment completed in the 1960s, which concluded that gravel did not affect stream temperature,” explains Johnson. “Although that study was advanced for its time, the advent of 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 was possible before.”

The high-tech approach has yielded some interesting results. By comparing changes in water temperature between stream reaches with bedrock versus gravel bottoms while also accounting for a host of outside influences, Wondzell and Johnson were able to account for the effect of substrate.

“Daily maximum temperatures were higher and minimum temperatures lower in the bedrock reach than in the gravel reach. Average daily temperatures, however, were similar,” says Johnson.

“Of issue is the heat transferred, through heat conduction, between water and the substrate. In conduction, heat moves from areas



A simplified heat budget shows the complexity of inputs and outputs of heat in a stream.

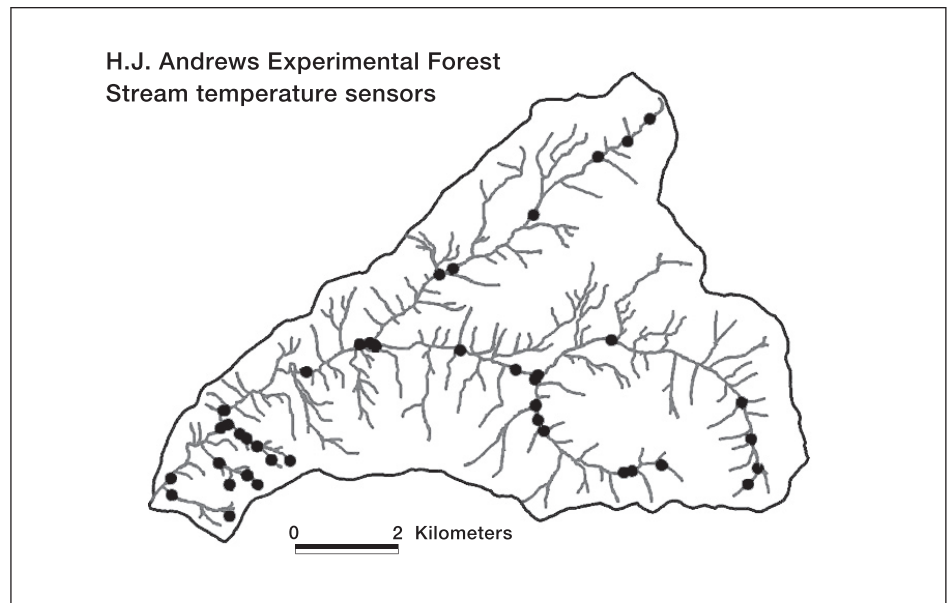
with higher temperature to those with lower temperatures. The effect of heat conductance is very difficult to measure in streams with large hyporheic zones. When water leaves the stream channel and enters the hyporheic zone, it slows down and comes in contact with gravel and sand; all the while, it is exchanging heat with the substrate.

Determining the amount of heat transfer requires, among other things, an accurate estimate of how much stream water is flowing through the hyporheic zone and how long it stays there.

Prior to Johnson’s shade study, Wondzell had used a network of wells and tracer dyes to estimate the time that the stream water

spends in the hyporheic zone. “We found that travel times in mountain streams are highly variable, ranging from minutes to days within one stream reach. The size of a stream and the shape of its channel—whether it is straight or meandering, single-thread or braided, steep or flat, free of debris or full of logjams—has great influence on the residence time,” says Wondzell.

Wondzell believes that the influence of hyporheic zones on stream temperature is an area ripe for future research. For now, however, we have come a long way just to understand that the substrate and the underground portions of streams do indeed moderate water temperature. This finding can help land managers who are concerned that their activities may influence stream temperature. For example, the type of substrate may be a good predictor of the magnitude of impact that a timber harvest near streams will have on stream temperature.



Stream temperatures are dynamic and respond to many influences. New technologies, such as inexpensive temperature sensors coupled with data loggers, allow researchers to measure how temperature varies across the landscape. The black dots represent temperature sensors.

DEVisING A BUDGET

There are several factors controlling temperature other than substrate. The rate of flow and the amount of water in a stream can influence the potential for fluctuations. The entrance of groundwater affects both the average temperature and the total amount of water. Even the shape of the stream channel—whether it is narrow and deep or shallow and wide—can influence the water temperature.

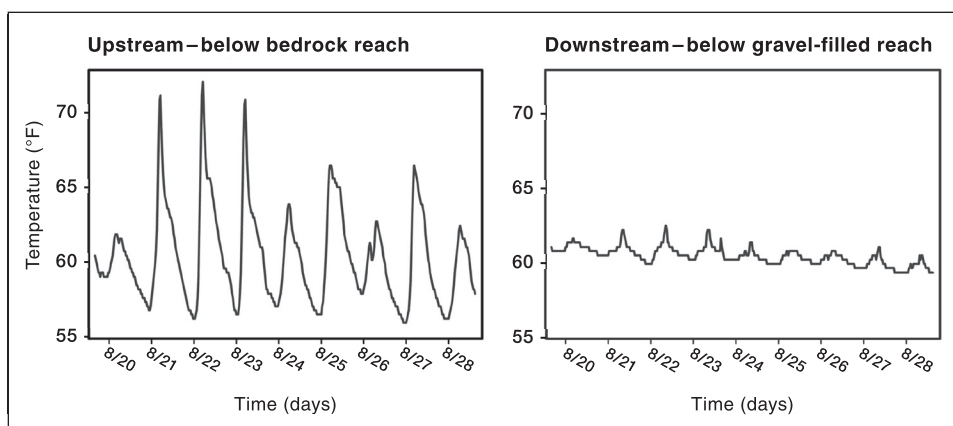
As if this weren’t complicated enough, a stream is continually moving and the conditions are constantly changing. There is simply no uniform stream temperature.

To begin to evaluate this complexity and determine the relative influences of multiple factors on stream temperatures, Johnson and Wondzell constructed heat budgets. Just like a household budget, a heat budget itemizes all the incoming and outgoing factors that affect the bottom line. Except, unlike household budgets, you can’t directly measure all the influences in a heat budget; some you have to estimate. The end result can be a diagram of circles and arrows indicating the fluxes of energy in and out of a stream.

“A heat budget is a physics problem; it traces the movement of energy through a complex

system,” explains Wondzell. “The same processes occur in streams anywhere in the world.”

“In our budgets, we directly measure as many components as we can, and we try to make these measurements as close to the stream as possible. This way, we can account for microclimatic differences that exist right next to the stream,” says Johnson. “We have



Stream temperature data was collected in August 1997 from a stream in the H.J. Andrews Experimental Forest in the central Cascade Range, Oregon. Over 8 days, stream water temperatures averaged 60.5 degrees Fahrenheit at the upstream and downstream sites, despite major differences in daily temperature range.



Portable climate stations, placed in several locations along the streambank, allow researchers to measure microclimatic conditions near streams

constructed several portable streamside climate stations that measure the wind speed, relative humidity, short and long wave solar radiation, and the air and water temperature. What we can't measure directly, we have to calculate; this includes processes like evaporation, conduction, and convection."

The heat budget determines the relative contribution of individual factors for any one point in time. For example, Johnson constructed two heat budgets for noon on July 20, 1997; one calculated under her shading experiment and another calculated in the full sun.

"Both heat budgets showed that air temperature comprises a relatively small portion of total heat flux, while direct solar radiation plays the dominant role," says Johnson.



LAND MANAGEMENT IMPLICATIONS



- Forest harvest along streams can affect stream temperature. The extent to which riparian areas can be thinned or harvested without increasing stream temperature differs from place to place. Understanding mechanisms of heat exchange can help management predict site-specific responses to thinning.
- The type of substrate may be a good predictor of the magnitude of effect that forest harvest can have on stream temperatures. Streams over bedrock may be more responsive to forest harvest, whereas those with hyporheic flows may be less responsive.
- The Federal Clean Water Act requires that streams with temperatures above critical thresholds be listed as "water quality limited." Stakeholder groups and state agencies can use stream heat budgets to better understand influences on stream temperature, which will assist in meeting regulatory requirements.

FROM SCIENCE TO POLICY

As Johnson and Wondzell's research has made clear, water temperature is influenced by many things. It is therefore easy to see how decades of irrigation, development, logging, agriculture, and stream channelization have altered historical temperature regimes.

Concern over rising stream temperatures led the Environmental Protection Agency (EPA) to include high temperatures in their list of potential pollutants under the Federal Clean Water Act. Currently, any stream with temperatures above a critical standard is listed on the "water quality limited" list.

Johnson recently led a science review process of the EPA's new water temperature standards for the Pacific Northwest region. "The new policy sets water temperature standards based on the needs of multiple species of fish at various life stages," explains Johnson.

"The policy does its best to meet the needs of fish, yet it cannot reflect the complexity of water temperatures found in streams and rivers. In the end, the policy is based on thresholds or just one number that is supposedly the 'right' temperature," says Johnson.

State Forestry Boards and other local agencies within the region are working to ensure that streamside buffers and Best Management Practices are adequate to

meet the Clean Water Act requirements. Landowners with water-quality-impaired streams are meeting with neighbors and Watershed Councils to create remediation plans to address high stream temperatures. Stakeholder groups from the agricultural and forestry sectors want to ensure that they are meeting their legal obligations and not harming streams without being saddled with overly expensive policies. With the stakes so high, the debate over stream temperature is frequently intense.

The contradictory results published in the scientific literature have added uncertainty and confusion. Fortunately, Johnson and Wondzell's research has gone a long way toward correcting inaccuracies of the past. And as Johnson notes, "Continued research will help to fill remaining gaps and clarify assumptions in our present understanding of stream temperature dynamics."

"Water is the most critical resource issue of our lifetime and our children's lifetime. The health of our waters is the principal measure of how we live on the land"

—Luna Leopold

FOR FURTHER READING

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SCIENTIST PROFILES



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sides of the Pacific Northwest, with continuing hyporheic studies in the H.J. Andrews forest and in southeast Alaska, and projects in the Blue Mountains of eastern Oregon and Washington studying the effects of prescribed fire on erosion and stream sedimentation.

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