Riparian Shade and Stream Temperature: An Alternative Perspective

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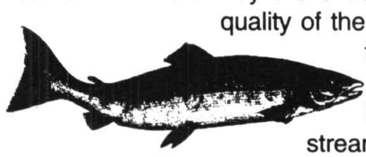
For streams in the upper Columbia River Basin, and elsewhere across much of the Intermountain West, the important role of shade with respect to stream temperatures has become an increasingly important issue. For example, the recent discussion of riparian systems by Larson and Larson (*Rangelands*, August 1996) focused on shade and temperature. However, I found that their perspective left much unsaid concerning the physical processes influencing stream temperatures and the role of riparian vegetation. There is no doubt that the reply that follows will also leave much unsaid, but I trust that readers will come away with a greater understanding about the relationship between riparian vegetation, shade, and stream temperatures.

In the Pacific Northwest, decreasing salmon populations over the past decades have resulted in an urgent need for improving the management of watersheds, fish habitat, and water quality. Wild salmon, which once numbered more than 10 million returning adults in the Columbia River basin alone, have declined to less than one-tenth that number up and down the coast of the Pacific Northwest (National Research Council 1996). A variety of natural factors (ocean conditions, climatic variations) and human factors (fishing, dams, hatcheries, urbanization, forest practices, agricultural practices, livestock grazing, and others) have affected salmon populations. Once salmonids leave the ocean and enter freshwater streams and rivers they are critically dependent upon the quality of the water and instream habitats, particularly for spawning and rearing. Unfortunately, many streams in the upper Columbia River Basin and elsewhere in the Intermountain West have experienced serious long-term declines in the quality of aquatic habitats for both anadromous and resident fisheries (e.g., McIntosh et al. 1994, Wissmar et al. 1994).



Various characteristics of a stream system, the adjacent riparian area, and upslope watershed conditions collectively influence instream habitats. However, a stream's summertime temperature regime is often a critical characteristic of habitat quality. Temperature not only regulates the biological activity of aquatic organisms (higher temperatures result in increased metabolic rates) but the capability of water to hold oxygen decreases with higher temperatures. With high summertime temperatures, salmonids and other cold water species may experience increased stress levels, greater susceptibility to disease, and an inability to compete with warm water species.

Larson and Larson (1996) indicate that the State of Oregon has established forest practices rules and regulations for riparian zones. Indeed, forest practices rules, recently modified to provide increased levels of protection to fisheries and other aquatic organisms (Oregon Department of Forestry 1994), have been in place for approximately twenty-five years. In contrast, comparable levels of water quality and stream protection for agricultural and rangeland streams do not exist in Oregon. A recent compilation by the Oregon Department of Environmental Quality (1996) indicates large numbers of streams and stream miles associated with agricultural and rangeland areas do not meet current water quality standards for temperature.

Stream Temperatures and Shade

Some of the early temperature research in the Pacific Northwest focused on the effects of removing forest vegetation from mountain streams. This early work led to a temperature prediction equation (Brown 1972) which illustrates several important principles regarding instream temperatures. These principles are also applicable to streams draining rangeland and agricultural areas. Brown's Equation is:

$$\Delta T = \frac{NH \times SA}{Q} \times C \qquad (1)$$

where ΔT = change in maximum daily stream temperature
NH = net heat exchange per unit of surface area
SA = surface area of stream for a specific reach
Q = streamflow or stream discharge
C = coefficient

For a given reach of stream (with a given surface area and streamflow), this simple model indicates that any increase in the amount of heat entering a stream from solar radiation (or other sources) will have a proportional increase in stream temperature. Similarly, this relationship indicates that instream withdrawals during summertime periods may exacerbate maximum temperatures.

A variety of heat sources and heat transfer mechanisms (i.e., the NH term in Browns Equation) ultimately influence the temperature of a stream. Energy exchanges may involve solar radiation, longwave radiation, evaporative heat transfer, convective heat transfer, conduction, and advection (e.g., Lee 1980, Beschta 1984). While the interactions of these variables is complex, and the importance of any given variable can significantly change during a day or over the course of a season (Beschta et al. 1987), certain of these variables are much more important than others.

Larson and Larson (1996) mention that direct sunlight only accounts for approximately twenty percent of the total ambient radiation (i.e., incoming direct and diffuse solar radiation, and incoming longwave). They seemingly disregard the fact that even though a stream is continuously receiving longwave radiation it is also emitting longwave radiation and that over a twenty-four-hour period the net longwave radiation essentially balances. This leaves solar radiation as the singularly most important radiant energy source for heating streams during daytime conditions.

The amount of heat available during clear-sky conditions in mid-summer is substantial (Fig. 1) and for an unshaded stream, over ninety percent of the incoming energy would become available to that stream (i.e., less than ten percent would be reflected). Most ranchers, foresters, and agricultural landowners know that when working outdoors in the middle of the summer it is always best to wear a hat. Hats obviously provide a variety of functions, but one of their important functions is to shade the upper portion of the body from the sun's rays (and its heat load). So it is with streams. Riparian vegetation similarly functions as a "hat" and prevents sunlight (and its associated heat load) from reaching the water surface.

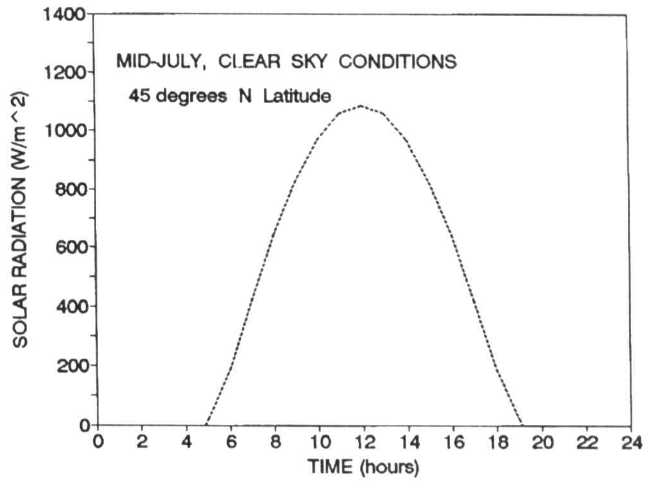


Fig. 1. *Solar radiation available at the surface of an unshaded stream (Beschta 1984).*

Although Larson and Larson (1996) indicate "It is true that shade can be used to intercept direct solar radiation over water", they conclude that "...in reality this interception will yield only limited benefit in many situations." These conclusions are apparently based on their rudimentary example of a relatively short (50-ft tall) tree along a 40-foot wide stream. While a single tree removed some distance from a channel will only shade part of a wide stream, a relatively continuous border of riparian trees (mature trees in the Intermountain West can also exceed 50-ft in height) located along the streambank as well as variable distances from the bank, can significantly reduce instream energy loads from solar radiation. This is particularly true for the vast majority of streams that don't match the strict constraints (i.e., an east-west oriented stream with no sinuosity) of the Larson and Larson example.

Larson and Larson's (1996) selection of a 40-ft wide stream for illustration purposes may not be relevant for many aridland stream systems. For example, the Upper Grande Ronde River Basin (drainage area of 389 square miles) in northeastern Oregon has approximately 360 miles of perennial fish-bearing stream and an additional 400 miles of non-fish bearing stream. Summertime field assessments indicate that over ninety percent of the 38 subwatersheds comprising the Upper Grande River Basin have fish-bearing streams with average wetted widths of 10 feet or less (Wallowa-Whitman National Forest 1991); widths for the non-fish streams would be even narrower. Only one of the 38 subwatershed streams, consisting of the mainstem Grande Ronde River, has a wetted width of 40 feet or greater. For this basin, and probably most others throughout the upper Columbia River Basin, the vast majority of stream miles important to the spawning and rearing needs of anadromous and resident fish are represented by streams much narrower than the 40-ft wide example developed by Larson and Larson.

The type of vegetation that is effective in providing shade varies among riparian zones and size of stream. Coniferous and deciduous trees can provide significant amounts of shade because of their heights and extensive canopies. Field measurements along streams with forested riparian systems in northeastern Oregon have measured shading levels of eighty percent or more (Bohle 1994). Mature trees can shade more stream surface area and extend their shadows farther across wide streams than vegetation shorter in stature; trees along a streambank are more effective at shading a stream than those farther away. For streams that flow through relatively open valley systems, a combination of willows (*Salix* spp.), other shrubs, and cottonwoods (*Populus* spp.) can collectively provide critical amounts of shade. Shrubs are important sources of shade for intermediate sized streams whereas sedges, rushes, and other herbaceous plants along streambanks can significantly contribute to overall levels of shading for small meadow streams. For the majority of aridland stream systems, vegetation can potentially provide significant levels of shading. Where this occurs, concurrent reductions in solar radiation levels (Fig. 1) and reductions in maximum stream temperatures (Browns Equation) will follow.

The continually changing spatial relationship between the sun, the canopy of riparian vegetation, and the amount of

solar energy reaching a stream from day-to-day during the summer is certainly more complicated than the above discussion would indicate. However, prevention of stream heating with riparian shade is an exceptionally important function of streamside vegetation and is the focus of this discussion. Unfortunately, the shading function of riparian vegetation has often been altered or reduced by a wide variety of management activities. Many historical land use practices (harvesting of riparian trees, shrub removal along streams, ditching and straightening of channels, season-long grazing in riparian areas, and others) have adversely affected riparian vegetation cover along many western streams (Kauffman and Krueger 1984, Platts 1991, McIntosh et al. 1994, Wissmar et al. 1994, National Research Council 1996).

If a manager's objective is to prevent excessively high summertime stream temperatures, then a well-vegetated riparian area which provides extensive amounts of shade to a stream would seemingly be the simplest and most effective way of doing so. Shade from streamside vegetation, in conjunction with other processes facilitated by intact riparian zones (e.g., hyporheic exchange), provides the mechanism(s) for preventing or minimizing high temperatures. This was how summertime stream temperatures were naturally moderated when relatively large populations of anadromous salmonids annually cycled into and out of Columbia Basin stream systems over thousands of years.

Riparian vegetation also plays another important role in mediating summertime stream temperatures. Where streamside vegetation has been removed or reduced by logging, grazing, or other means, a loss of root strength encourages streambank erosion and channel widening during highflow events (See Elmore and Beschta 1987, Fig. 2). Additional stream width typically results in relatively shallow stream depths during summertime flows and thus contributes to increased summertime temperatures. Channel widening also reduces the shading effectiveness of any remaining streamside vegetation. Conversely, the reestablishment of healthy riparian vegetation can cause formerly degraded channels to narrow. Thus, vegetation has multiple roles that directly (*via* shading) and indirectly (via its affects on channel morphology) influence and regulate stream temperatures in forest and range environments.

Lastly, riparian vegetation that furnishes shade and resists fluvial erosion also influences litter inputs, insect drop, large and small woody debris recruitment, nutrient transformations, and other ecological processes that are integral components of intact aquatic habitats (Elmore and Beschta 1987). Thus, while temperature is a "stand alone" variable with regard to water quality and aquatic habitat, it is also an important indicator of numerous other ecological processes and functions of healthy aquatic/riparian ecosystems.

Conclusions

Research and field observations regarding the historical effects of land uses indicate that a great many streams in the upper Columbia River Basin and elsewhere in the western U.S. have levels of riparian vegetation much reduced or greatly altered from what was present prior to Euro-American settlement. The pre-settlement condition of many western streams and riparian systems can often be inferred by inspection of streamside soil profiles which are all too frequently exposed because of eroding streambanks. For those that take the time to examine and understand the extent of human impacts to channels and riparian plant communities, particularly since the turn of the century, the magnitude of change is often astonishing (e.g., Chaney et al. 1990, Platts 1991, Wissmar et al. 1994). Even so, functional riparian plant communities that produce adequate stream shade and provide improved bank stability can usually be reestablished and restored, often over relatively short periods of time. Recovery of riparian vegetation can also provide a parallel improvement in stream temperatures, overall water quality, and instream habitats for a variety of fish and aquatic organisms. Improving riparian vegetation and channel conditions may also beneficially affect moisture regimes of meadow systems and increase forage productivity.

There are major opportunities for improving water temperatures and aquatic habitats for many streams in eastern Oregon and the upper Columbia River Basin. Increased levels of shading for water quality limited streams would greatly improve summertime stream temperatures in most situations. In many instances it may even be possible to reduce maximum temperatures so they no longer exceed state water quality standards. As a society, we may continue the debate whether western streams really have a temperature problem (they do), what are the causal mechanisms (shade really is important), and who is responsible. However, it is clear that achieving improved levels of riparian shade and decreased summertime temperatures will require landowners to change those management practices that have contributed to current conditions. It is also clear, that without such changes, fish and other aquatic organisms will continue to feel the heat.

Literature Cited

Beschta, R.L. 1984. TEMP-85; A computer model for predicting stream temperatures resulting from the management of streamside vegetation. USDA Forest Service, Watershed Systems Development Group, Ft. Collins, Colorado. WSDG-AD-00009, 76 pp.

Beschta, R.L., R.E. Bilby, G.W. Brown, L.B. Holtby, and T.D. Hofstra. 1987. Stream temperature and aquatic habitat: Fisheries and forestry interactions. Pp. 191-232. *In*: E.O. Salo and T.W. Cundy (eds), Streamside Management: Forestry and Fishery Interactions. University of Washington, Institute of Forest Resources, Contribution No. 57. 471 pp.

Bohle, T.W. 1994. Stream temperatures, riparian vegetation, an channel morphology in the Upper Grande Ronde River Watershed, Oregon. Department of Forest Engineering, Oregon State University, Corvallis, Oregon.

Brown, G.W. 1972. An improved temperature model for small streams. Water Resources Research Institute Report 16, Oregon State University, Corvallis, Oregon.

Chaney, E., W. Elmore, and W.S. Platts. 1990. Livestock grazing on western riparian areas. Northwest Resource Information Center, Inc., Eagle, Idaho. 45 pp.

Elmore, W. and R.L. Beschta. 1987. Riparian areas: Perceptions in management. Rangelands 9(6):260–265.

Kauffman, J.B. and W.C. Krueger. 1984. Livestock impacts on riparian ecosystems and stream management implications: A review. J. of Range Management 37:430–437.

Larson, L.L. and S.L. Larson. 1996. Riparian shade and stream temperature: A perspective. Rangelands 18(4):149-152.

Lee, R. 1980. Forest Hydrology. Columbia University Press, New York. 349 pp.

McIntosh, B.A., J.R. Sedell, J.E. Smith, R.C. Wissmar, S.E. Clarke, G.H. Reeves, and L.A. Brown. 1994. Management history of eastside ecosystems: Changes in fish habitat over 50 years, 1935 to 1992. USDA Forest Service, General Technical Report PNW-GTR-321. 55 pp.

National Research Council. 1996. Upstream: Salmon and society in the Pacific Northwest. National Research Council (U.S), Committee on Protection and Management of Pacific Northwest Anadromous salmonids, National Academy of Sciences. 452 pp.

Oregon Department of Environmental Equality. July, 1996. DEQ's 1994-96 list of water quality limited water bodies and Oregon's Criteria used for listing water bodies. Portland, Oregon.

Oregon Department of Forestry. 1994. Forest practice water protection rules, Division 24 and 57. Salem, Oregon. 59 pp.

Platts, W.S. 1991. Livestock grazing. Pp. 389–423. *In*: W.R. Meehan (ed). Influences of Forest and Rangeland Management on Salmonid Fishes and their Habitats. American Fisheries Society, Bethesda, Maryland, Special Publication 19. 751 pp.

Wallowa-Whitman National Forest. 1991. Stream Survey Data, La Grande Ranger District. La Grande, Oregon.

Wissmar, R.C., J.E. Smith, B.A. McIntosh, H.W. Li, G.H. Reeves, and J.R. Sedell. 1994. Ecological health of river basins in forested regions of eastern Washington and Oregon. USDA Forest Service, General Technical Report PNW-GTR-326. 65 pp.

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