TEMPERATURE: DETAILED CONCEPTUAL MODEL NARRATIVE

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Temperature directly influences the physical, chemical, and biological processes and attributes of aquatic ecosystems. As a result, changes in water temperature and thermal regime can significantly impact the structure and function of aquatic communities.

Model Format

The temperature conceptual model diagram depicts sources and land use and channel alterations that alter the delivery of heat to streams near the top of the figure, leading down the diagram to steps in the causal pathway, proximate stressors, modes of action, and eventually biological responses at the bottom. This narrative generally follows the diagram from top to bottom, left to right. For more information on interpreting CADDIS conceptual model diagrams, see the Conceptual Model Library homepage.

This temperature model is most applicable to wadeable streams. Temperature dynamics in larger streams may be driven by different factors; for example, some human activities included here (e.g., removal of riparian vegetation) will have less impact on larger streams that rely less on riparian trees for shading.

Linking Sources to Proximate Stressors

There are a few direct anthropogenic inputs that affect water temperature. For example, upstream impoundments may increase or decrease stream temperatures depending on the type of release (i.e., hypolimnetic vs. epilimnetic), and discharge of heated industrial effluents can increase stream temperatures and affect the rate of temperature change (e.g., causing a rapid drop in stream temperatures during periods of discharge cessation). However, most human activities alter stream thermal regimes through land cover alteration and subsequent changes in the delivery and distribution of heat from the ultimate source – solar radiation.

Watershed land cover alteration (e.g., vegetation removal) can increase warmwater inputs by increasing solar heating of the land and heated surface runoff from impervious surfaces. Riparian land cover alteration and devegetation increases stream temperatures by increasing solar radiative heating, either by directly decreasing canopy cover and shading or by increasing stream bank erosion and stream channel width (i.e., leading to slower, shallower water and decreased importance of canopy cover). These land cover changes also may affect thermal buffering capacity. For example, groundwater inputs can help mediate temperature increases, as groundwater often is cooler than surface waters, especially in summer. If groundwater inputs are reduced (e.g., due to decreased infiltration and groundwater recharge), coldwater inputs may decrease and this temperature-buffering capacity may be lost.

Downstream impoundments increase water retention time and surface area, increasing the temperature of impounded water. Surface water withdrawals decrease the volume of water, decreasing buffering capacity. Channel alteration, including tiling, also can affect the ability of a stream to “buffer” various heating processes by reducing hyporheic exchange and groundwater recharge. Groundwater withdrawals not only decrease the volume of water, but also coldwater inputs [for a more detailed examination of stream temperature processes, see Poole and Berman (2001)].

Changes in water temperature can be closely related to several other stressors. For example, DO saturation concentration decreases and dissolution of ionic compounds increases at warmer temperatures, so temperature increases can contribute to problems with these stressors. Increases in suspended sediments can increase temperature by increasing heat absorption, and reductions in baseflow (i.e., groundwater discharge) also can lead to water temperature increases.

Linking Proximate Stressors to Biological Impairment

Altered stream temperature regimes can cause biological impairment through a variety of direct and indirect mechanisms. Acute lethality to organisms occurs when maximum stream temperatures exceed thermal tolerances for a sufficient period of time, or when the rate of water temperature change is so fast that organisms are unable to acclimate. Consequently, shifts in community structure, from coldwater to warmwater taxa, may be observed. In fact, many coldwater species are limited in their distribution by maximum stream temperatures during summer; conversely, the distribution of warmwater species may be limited by minimum winter temperatures, and thus, reductions in minimum stream temperatures may be particularly relevant for these taxa (Scheller et al. 1999).

Chronic thermal stress can manifest in aquatic organisms through a variety of mechanisms, including increased parasitism and disease and changes in behavior or condition. Increased temperatures also lead to higher metabolic rates, and associated increases in energy requirements; if increased energy requirements are not accompanied by increased food intake, then organism health and fitness can be impaired.

The timing of temperature changes also is of critical importance to the ecological health of aquatic ecosystems. For example, developmental and reproductive cycles of many species are closely tied to seasonal changes in stream temperatures and/or the rate of heat accumulation in the stream. Changes in timing of such thermal cues, due to either increased or decreased temperatures, can alter the timing of insect emergence, fish migration, and other activities, disrupting natural life cycles and predator-prey relationships. Any of these direct or indirect temperature effects can contribute to biological impairment of aquatic communities.

REFERENCES

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.

Scheller RM, Snarski VM, Eaton JG, Oehlert GW. 1999. An analysis of the influence of annual thermal variables on the occurrence of fifteen warmwater fishes. Transactions of the American Fisheries Society 128:257-264.