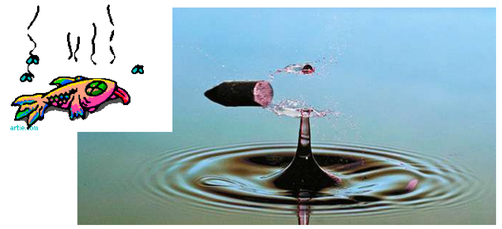
Climate Velocity in Streams…

What Does it Mean for Fish?

Daniel J. Isaak and Bruce E. Rieman

Air, Water & Aquatics Program

U.S. Forest Service, Rocky Mountain Research Station, Boise, ID USA.



Introduction

As global warming increases Earth's temperatures, isotherms shift toward higher elevations in mountains and poleward in flat terrain. Loarie et al. (2009) have described the rate of isotherm shifts as the "velocity" of climate change in terrestrial ecosystems. Population boundaries that are thermally mediated must track shifting isotherms to remain in equilibrium with the distribution of thermally suitable habitat (Figure 1).

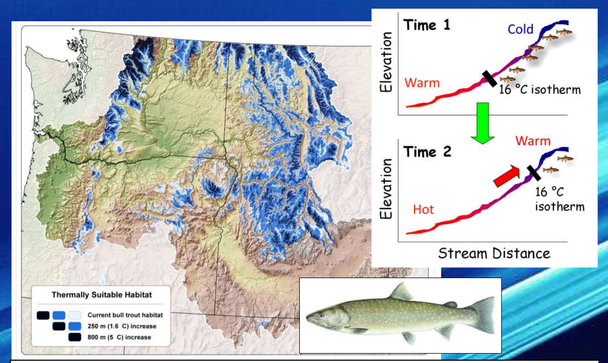


Figure 1. Model predictions of thermally suitable historic and future bull trout natal habitats from Rieman et al. (2007). This model and many similar models for other fish species assume that distributions will track isotherms as they shift during climate warming.

Dozens of bioclimatic models for stream fish developed in the previous two decades forecast significant shifts in thermal habitats (and dramatic range contractions for many species) but biological evidence confirming these predictions is virtually nonexistent. Evidence is lacking due to inadequate long-term monitoring efforts near species boundaries and because model predictions are too imprecise to guide these efforts. Here, we develop equations for calculating isotherm shift rates (ISRs) in streams. These equations can be calibrated to individual streams using easily collected measurements of stream slope from a GIS and temperature from digital sensors (Isaak et al. 2010; Isaak and Horan 2011) to facilitate precise predictions of historic and future warming scenarios.

ISR Calculations

Three measurements are required to calculate a stream ISR, the: 1) spatial temperature gradient within a stream (i.e., its lapse rate), 2) long-term warming rate, and 3) stream slope. The first step in an ISR calculation determines the vertical displacement (*a*) of an isotherm associated with a long-term warming rate (Figure 2) by dividing the stream lapse rate into the warming rate:

$$a = (°C/decade) / (°C/100m) \qquad (1)$$

The second step in an ISR calculation translates *a* to the rate of shift along a stream using the trigonometric relationship for a right triangle:

$$c = a / \sin(A°) \qquad (2)$$

where $A°$ = stream slope (Figure 2).

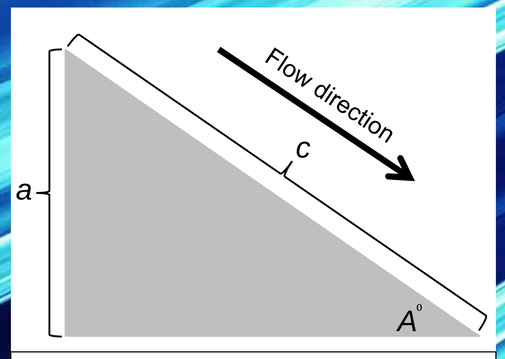


Figure 2. Schematic representing a stream isotherm shift as parts of a right triangle.

For easy reference, the ISR calculations were made for a range of stream conditions and summarized in a set of curves (Figure 3). Results suggest that isotherms shift much more rapidly in flat streams (1.5 – 60 km/decade in slopes of 0.1% – 1%) than in steep streams (0.1 – 3 km/decade in slopes of 2% - 10%) as warming occurs. The rate of warming also affects ISRs but the effect scales linearly so that a doubling of the warming rate translates to a doubling of the ISR.

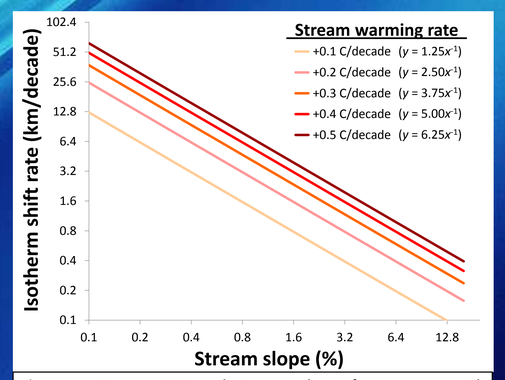


Figure 3. Stream ISRs relative to slope for streams with elevational lapse rates of 0.8 °C/100 m and long-term warming rates that span a range of realistic values (Isaak et al. 2012).

Mapping Climate Velocity

The ISR equations can be used to develop climate velocity maps (*sensu* Loarie et al. 2009) that display shift rates geographically. The example below shows ISRs for a river network, and again highlights the fact that climate change causes faster isotherm shifts in streams with low slopes.

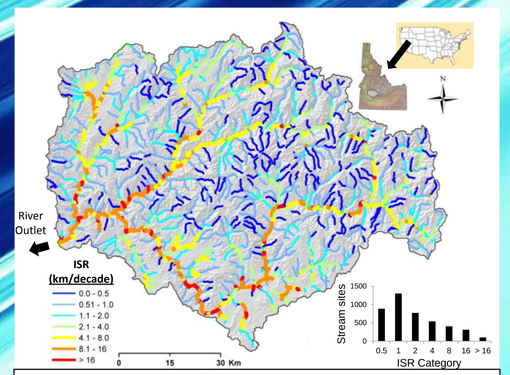


Figure 4. Velocity map for the Boise River network in central Idaho. ISRs were calculated assuming a warming rate of 0.2 °C/decade and a common lapse rate among streams. Mainstem rivers and low slope reaches are discernible by their orange and yellow colors indicating faster changes.

ISR Power Analysis

Short-term, inter-annual and decadal, variation in stream temperatures is large relative to the gradual temperature increases associated with climate change. This variability will partially mask isotherm shifts from fish populations, so a power analysis was conducted to determine the time required for statistically significant isotherm shifts to occur. This time period was negatively related to ISR and positively related to inter-annual temperature variability (Figure 5). For realistic warming rates of 0.1 – 0.3 °C / decade, 2 – 6 decades may often be required for significant isotherm shifts to occur.

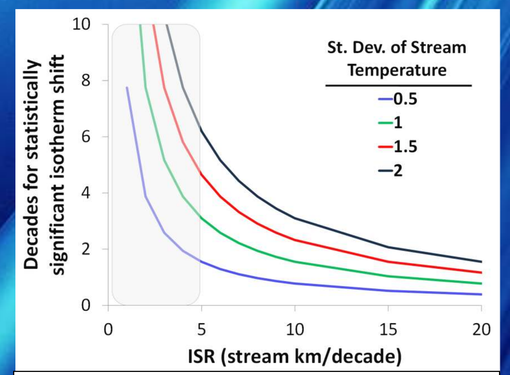


Figure 5. Decades required for a statistically significant isotherm shift to occur based on ISR and the amount of inter-annual temperature variation (Standard Deviation). Shaded area highlights realistic ranges associated with long-term warming rates of 0.1 °C – 0.3 °C / decade.

Discussion

Global warming this century is expected to profoundly affect fish populations but many of the details are yet to be resolved. The ISR framework provides improved resolution regarding anticipated thermal effects on species and population distributions. ISR predictions suggest that thermally mediated distribution boundaries occurring in streams with low slopes will experience rapid changes as warming proceeds. Distribution boundaries in steeper streams will experience slower changes but even small changes could be important where upstream refugia are lacking or limited in size.

The ISR equations provide useful predictions, but these must ultimately be compared against fish distribution data to assess their validity. The power analysis suggests several decades will elapse for significant isotherm shifts to occur in most locations. Newly initiated biological monitoring efforts, therefore, will not yield estimates of climate-related distribution shifts in time for useful conservation planning (i.e., < 10 years). Resampling of historical fish survey sites could provide these estimates in the near future (i.e., 2 – 3 years) and should be prioritized to document fish responses to climate change. These estimates are critical for validating and improving the bioclimatic models that will be necessary for strategic conservation planning this century.

For more details about this research, see Isaak and Rieman (2012).

References

Isaak, D.J., and B.E. Rieman. 2012. Stream isotherm shifts from climate change and implications for distributions of ectothermic organisms. *Global Change Biology* doi:xxx.

Isaak, D.J., and D.L. Horan. 2011. An evaluation of underwater epoxies to permanently install temperature sensors in mountain streams. *North American Journal of Fisheries Management* **31**:134–137.

Isaak D.J., D.L. Horan, and S. Wollrab. 2010. A simple method using underwater epoxy to permanently install temperature sensors in mountain streams. Available at: http://www.fs.fed.us/rm/boise/AWAE/projects/stream_temperature.shtml.

Isaak, D.J., S. Wollrab, D. Horan, and G. Chandler. 2012. Climate change effects on stream and river temperatures across the northwest U.S. from 1980–2009 and implications for salmonid fishes. *Climatic Change* **113**:499-524.

Loarie, S.R., P.B. Duffy, H.H. Hamilton, G.P. Asner, C.B. Field, and D.D. Ackerly. 2009. The velocity of climate change. *Nature* **462**: 1052-1055.

Rieman, B.E., D.J. Isaak, S. Adams, D. Horan, D. Nagel, C. Luce, and D. Myers. 2007. Anticipated climate warming effects on bull trout habitats and populations across the interior Columbia River Basin. *Transactions of the American Fisheries Society* **136**:1552-1565.

More Information…

Google "Climate Aquatics Blog" or "Stream temperature forest service" for more related research…