Slow Climate Velocities of Mountain Streams Impart Thermal Resistance to Headwater Refugia Across the West

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Common Perception:
Cold-Water Fish World is Ending...

- Meisner 1988
- Keleher & Rahel 1996
- Eaton & Schaller 1996
- Reusch et al. 2012
- Rahel et al. 1996
- Mohseni et al. 2003
- Flebbe et al. 2006
- Rieman et al. 2007
- Kennedy et al. 2008
- Williams et al. 2009
- Wenger et al. 2011
- Almodovar et al. 2011
- Etc.

• Huge declines: 50%-100%
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- Etc.

- Huge declines: 50% - 100%
- Imprecise air temperature models

Double-Whammy in Mountain Headwaters!

We’ve been predicting doom for almost 30 years
Climate “Velocity” is What’s Biologically Relevant
Rate at Which Isotherms & Thermal Niches Shift

Velocity varies 100x for same warming rate

Application to Streams Required Some Data

>150,000,000 hourly records
>20,000 unique stream sites
>100 resource agencies
& Some High-Resolution Scenarios

- $R^2 = 0.91$
- RMSE = 1.0°C
& Some High-Resolution Scenarios

• $R^2 = 0.91$
• $RMSE = 1.0$º

1-km resolution
500,000 kilometers
Stream Warming Rates 1968-2011

923 sites in NorWeST database with >10 year records

+0.11°C/decade
Stream Warming Rates 1968-2011

923 sites in NorWeST database with >10 year records

+0.11°C/decade

0.21°C/decade

Weather Stations
Coldest Streams Warming More Slowly

So...

~0.07 °C/decade

0.32 °C/°C

0.5 °C/°C

August stream temperature (°C)

Sensitivity (°C/°C)
BUT... Velocity is What Matters!

Stream Velocity Reference Equations

Stream warming rate
- +0.1 C/decade \((y = 1.25x^{-1})\)
- +0.2 C/decade \((y = 2.50x^{-1})\)
- +0.3 C/decade \((y = 3.75x^{-1})\)
- +0.4 C/decade \((y = 5.00x^{-1})\)
- +0.5 C/decade \((y = 6.25x^{-1})\)

Climate Velocity Map for Regional Network

1968-2011 Median Stream Velocity: 1.07 km/decade

>10x Slower Than Velocities of Global Marine & Terrestrial Environments (Burrows et al. 2011)

Isaak et al. In Review
Where do Those “Doomed” Headwater Species Live?

Climate scenario & velocity maps

222,000 kilometer network
Where do Those “Doomed” Headwater Species Live?

Median velocity: 0.33-0.48 km/decade

BIG biological databases – 1000s of sites
Cold Climates Also Exclude Most Invasive Species from Mountain Headwaters

Proportion of sites species observed

Mean August Stream Temp (°C)

- Cutthroat Trout <125 mm (2269 sites)
- Bull Trout < 150 mm (1102 sites)
- Brook Trout (3061 sites)
- Brown Trout (832 sites)
- Rainbow Trout (1562 sites)

BEWARE THE INVASION
The Cold-Water Climate Shield
Delineating Refugia for Preserving Native Trout

Dan Isaak, Mike Young, Dave Nagel, Dona Horan, Matt Groce
US Forest Service - RMRS
Precise Species Distribution Models to Highlight Climate Refugia

BIG FISH DATA

>4,000 sites

NorWeST

Stream Temp

Climate Shield

Occurrence probability maps

2040s Occurrence Probability Maps

Cutthroat Trout
7,914 >0.1 habitats
7,153 >0.5 habitats
2,179 >0.9 habitats

Many Streams Will Continue to Support Populations!

Bull Trout
3,304 >0.1 habitats
641 >0.5 habitats
130 >0.9 habitats
Website Provides Information in User-Friendly Digital Formats

File formats:
- ArcGIS files
- pdf files

15 Scenarios:
- 3 climate periods
- 5 Brook invasion levels

Presentations & Publications

Digital Maps & ArcGIS Shapefiles

Fish Data Sources

Distribution Monitoring

http://www.fs.fed.us/rm/boise/AWAE/projects/ClimateShield.html
High-quality Spatial Information Empowers the Aquatic Army...

**Occupancy Probability**
- $> 0.90$
- $> 0.75$ to $< 0.90$
- $> 0.50$ to $< 0.75$
- $> 0.25$ to $< 0.50$
- $< 0.25$

**Slope** = 10% to 15%
High-quality Spatial Information Empowers the Aquatic Army...

Occupancy Probability

- > 0.90
- > 0.75 to < 0.90
- > 0.50 to < 0.75
- > 0.25 to < 0.50
- < 0.25

Slope = 10% to 15%

Highest priority conservation investment!
If It’s Steep, It Slows the Creep…

Many Headwater Refugia in Western Landscapes