Climate Warming Rates of Salmon and Trout Rivers in the West

+0.3°C/decade in summer

Madison River
The Billion $ Network of Concern

60,000 kilometers of rivers >100 cfs annual flow

Columbia R.
Snake R.
Missouri R.

300 million US$/spent annually on CRB fish & wildlife conservation through the Northwest Power Act of 1980 – Rieman et al. 2015
High Value Resources & Key Habitats
Thermal Constraints on Cold-Water Fish Populations are Common...

**Symptoms include...**
1) Migration delays & clustering in coldwater refuges
2) Selective gradients based on run timing
3) Mass mortality events:
   a) upriver stocks of Fraser river sockeye “disappear”
   b) spawning ground fish kills
Keefer et al. 2010; Crozier 2011; Caudill et al. 2013
4) Fishing season closures
5) Fish disease outbreaks?
6) Shifting distributions
Eby et al. 2014; Al-Chokhachy et al. 2016
Thermal Constraints Will be More Common

1880-2014 Global Air Temperature Trend

2014 Set a Record
Thermal Constraints Will be More Common

2015, 2016, ...
New bad records!
Regional Air Temp Trends (1976–2015)

Global Historical Climatologic Network V3 Dataset

**Summer** = 0.35°C / decade

**Fall** = 0.30°C / decade

**Winter** = 0.31°C / decade

**Spring** = 0.11°C / decade
What are the trends in Salmon and Trout Rivers?

Fraser River - Annual
\[ \Delta = 0.18^\circ C/\text{decade} \]

Snake River, ID - Summer
\[ \Delta = 0.27^\circ C/\text{decade} \]

Columbia River - Summer
\[ \Delta = 0.40^\circ C/\text{decade} \]

Missouri River, MT - Summer
\[ \Delta = 0.33^\circ C/\text{decade} \]

Morrison et al. 2001
Crozier et al. 2008
Stream Temperature Records in 2015
NFK Clearwater River in North Idaho

Daily Water Temp (°C)

36 years of data

Low flow

+
Where are Best Long-term River Records?

>220,000,000 hourly recordings
>22,700 stream sites

Database query:
1) How many sites have >10 years of August monitoring?
2) How many sites occur on rivers with >100 cfs flow?

Result: 391 river sites
Monitoring Record Length by Month at 391 sites

Average length: 16 years
Maximum: 36 years
Methods for Completing Time-Series:
• Summarized monthly air temperatures for forty year period of 1976-2015 from Global Historical Climate Network V3 dataset for 168 sites

• Summarized monthly river discharge from USGS NWIS, BOR HydroMet, & DART for 320 gage and dam sites

• Aligned data series for RivTemp, air temperature, and discharge into twelve monthly matrices (40 years x 879 sites)

• Imputed missing monthly RivTemp values using PCAs calculated with the MissMDA package in R (Missing Values with Multivariate Data Analysis)

• Retained completed RivTemp time series if $r > 0.8$ between observed and fitted values (average $r = 0.9$)

• Regressed RivTemp on year & calculated decadal trends for 20 & 40 year periods that end in 2015

0.11 °C / Decade

0.04 °C / Decade

0.05 °C / Decade

-0.03 °C / Decade

0.02 °C / Decade

0.01 °C / Decade

0.27 °C / Decade

0.14 °C / Decade

0.15 °C / Decade

0.05 °C / Decade

0.09 °C / Decade

0.07 °C / Decade
What’s Driving River Temperature Trends?

Monthly regional averages

40 year trends (1976-2015)
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Monthly regional averages

40 year trends (1976-2015)

Biological Consequences for Trout & Salmon?

A. Thermal exposure during adult salmon migration

\[ \text{Exp} = \text{Distance} \times \text{temperature} \times \text{time} \times \text{species-specific physiological parameter (sockeye, summer Chinook, summer steelhead)} \]

B. Thermal habitat distribution shifts for resident species

Time 1 vs. Time 2
Realized Thermal Niche Descriptions

NorWeST Stream Temperature

Frequency of Occurrence

BIG FISH Data

>13,000 surveys

Mapping Thermal Habitat Distributions

Thermal Habitat Maps:
Baseline: 1993-2011 (Scenario 1)
Mid century: +1 °C (Scenario 23)
Late century: +2 °C (Scenario 25)

August mean RivTemps:

- <12 °C = Cold
- 12–18 °C = Optimal
- >18 °C = Warm (~22 °C MWMT)

Cold
Optimal
Warm

NorWeST Stream Temp

Stream Temperature

<8
8-10
10-12
12-14
14-16
16-18
18-20
>20
Thermal Habitat Distributions for Brown & Rainbow Trout in Montana Rivers

Baseline

+0°C
Thermal Habitat Distributions for Brown & Rainbow Trout in Montana Rivers

+1°C
Thermal Habitat Distributions for Brown & Rainbow Trout in Montana Rivers

+2°C

At risk rivers:
- Bitterroot
- Madison
- Lower BlackFoot
- Middle Yellowstone
- Big Hole
- Upper Clark Fork
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<table>
<thead>
<tr>
<th>River kilometers that are:</th>
<th>&lt; 12°C</th>
<th>12-18°C</th>
<th>18-21°C</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Historical scenario</td>
<td>863</td>
<td>5,289</td>
<td>1,723</td>
<td>7,875</td>
</tr>
<tr>
<td>Mid century +1°C scenario</td>
<td>472 (-45%)</td>
<td>4,729 (-11%)</td>
<td>2,369 (37%)</td>
<td>7,570 (-4%)</td>
</tr>
<tr>
<td>Late century +2°C scenario</td>
<td>194 (-78%)</td>
<td>3,871 (-27%)</td>
<td>2,857 (66%)</td>
<td>6,922 (-12%)</td>
</tr>
</tbody>
</table>
Options for Cooling Smaller Rivers

1) Maximize riparian shade
2) Maximize summer flows
3) Restore channel complexity to force hyporheic exchange

4) Identify, protect, & enhance cold microrefugia
Options for Cooling Largest Rivers are Limited...
Options for Cooling Largest Rivers are Limited...

Artificial Icebergs like Dworshak

Deep reservoir needed for cold water creation
How Much Warmer Will it Get?

The Specifics are an “Unknowable Unknown”
How Much Warmer Will it Get?

Plan on continued warming for decades...

Atmospheric CO2 Concentration

Foot still on the greenhouse gas pedal...

+3 ppm/year
Human Adaptation in Future Decades

1) Accept that fish communities in some rivers will change & communicate that information to public
   At risk Montana rivers: Bitterroot, Madison, Lower BlackFoot, Middle Yellowstone, Big Hole, Upper Clark Fork

2) Continue enjoying cold-water fisheries in many rivers this century
   Refuge rivers: Rock Creek, Gallatin, NFK/SFK/MFK Flathead, Kootenai...

3) Diversify tackle box to include plugs for bass, snakeheads, & TBD critters

It’s Bubba-time!
Biocomplexity Will Provide a Buffer

Extinction is unlikely...

...But some species (or runs) may experience long-term declines

Summer runs

Fall/winter runs