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Climate Change & Aquatic Resources in the West: Where are We? What Does the Future Hold?

So I did my Ph.D. research under Wayne's tutelage on stream fishes across the Salt River watershed that straddles ID/WY border oh, 15 years ago now, wrote a bunch of papers, thought I was pretty hot shit, but there was one question I was asked by my dissertation committee that day that has always stuck with me, & that was by Dirk Miller. "Dirk, do you remember what that was?" It was, "how can managers use any of this stuff?" & unfortunately I didn't have a very good answer for him that day but he was still kind enough to pass me, which gave me an opportunity to get a job & keep working in the field & to try to find an answer to that question that has long haunted me, & in the last several years, in part driven by the concern over climate change, & enhanced by the digital revolution, I think things are really starting to come full circle, because in many cases, the models are so much more accurate, the databases, so much bigger, and growing rapidly, that there's a real opportunity for the research & management to come together in ways that create precise, accurate inventories of key aquatic features at high resolution across really broad areas such that it addresses a whole host of fundamentally important issues we've long struggled with, like "what are the spatial patterns in distribution/abundance of species and their habitats & how do those vary through time across river networks", basic questions, but one to which if we had good answers, much of the uncertainties involved in management would go away.

And so we're building some of those things in the northern Rockies across the bull trout range, and the capacity to have similar tools, even without nearly as much data & resources are equally great here in the CRCT range I think, and so want to present some of that wrapped in a cc story today. And hopefully then, by the end of this talk, I can convince Dirk into giving me a less grudging passing grade than he did a decade ago. OK, so…
General outline:

1) What are global climate trends & how is western US being affected?

2) What do climate trends mean for stream environments and fish populations?

3) How climate change & technology are spurring innovations in collaborative resource management

4) Key future uncertainties (resolvable & not)
Charismatic MegaFishes of Concern

Trouts & salmons, important for fish, commercial Many listed, tends to make data rich environment with All the various agencies studying
Temperature is Primary Control for Cold-Blooded Organisms Like Fish

McMahon et al. 2007

Brown 2004

Metabolism

In the lab...

Growth

McMahon et al. 2007

Brown 2004

Thermal Niche

Scope for aerobic performance

Onset of anaerobiosis

Onset of denaturation

Critical temperature

Optimum temperature

Denaturation temperature

Isaak & Hubert 2004

Biomass

Mean Stream Temperature (°C)
How Will Global Climate Change Affect my Stream?

Global climate model

Regional climate model

Stream reach

River network temperatures
20\textsuperscript{th} Century Observed Trend

1880 - 2008 Global Air Temperature Trend

+0.6 °C during 20\textsuperscript{th} Century
Larger changes coming

By 2050

2.5 °C

1.0 °C

0.6 °C ... so far

Mote et al. 2008
Short-term Variation in Warming

National Survey Finds Public Concern About Global Warming Drops Sharply
January 29, 2010, CBB

Temperature Anomalies Jan-Sep 2010
(with respect to a 1971-2000 base period)
National Climatic Data Center/NESDIS/NOAA

August Seas Warmest in at Least 120 Years

NOAA: Year-to-Date Global Temperature Ties for Warmest on Record
Arctic sea ice reaches its third lowest minimum extent on record
October 15, 2010
It’s Back…

& it’s not going away

% US in Extreme Drought
Western US Observed Climate Trends (1950 – 2009)

Air temperatures

Total Annual Precipitation

Smaller & earlier snowmelt & river runoff

Stewart et al. 2005
Runoff Timing Interacts with Precipitation
Wildfires Increasing Westwide

Fires > 10,000 Acres on USFS Lands


Fires from 2001 - 2007 on USFS Lands

National Research Council. 2011
Sediment Regimes

Fire & Disturbance

1996
Temperature Trends in Northwest 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
\[ \Delta = 0.33^\circ C/\text{decade} \]

Temperature Trends In Western Lakes

+1.1°C/decade from 1992-2008

Schneider et al. 2009.
Western landscapes (and streams) are highly dynamic and aquatic organisms are adapted accordingly.
“Balance of Nature”
Paradigm no Longer Valid
There Will be Winners & Losers
Species Phenologies are Accelerating

Average phenology change
+2.3 days/decade

Shifts in Salmon Migration Timing

Median Spring Chinook Migration Dates at Bonneville

Distribution of Sockeye Migrations at Lower Granite

Date

Studies...

• Juanes et al. 2003
• Crozier et al. 2008
• Keefer et al. 2009
• Wedekind & Kung 2010
• Crozier et al. 2011
• Etc.
Species Distributions are Shifting

Average distribution shift
6.1 km/decade poleward
OR
6.1 m/decade higher elevation

Brown Trout Distribution Shifts
Switzerland (1978-2002)

Stream Temp Increases

Disease Outbreaks

Elevation

Hari et al. 2006
Arctic Char Declines in the U.K.
Declining Fastest at Southern Range Extent

Climate is Causing Stream Fish Distributions to Shift...

Fish surveys $(n = 3,500)$

French stream fish distributions (1980’s vs 2000’s)

...but shifts are slower than Climate Velocity

Western US Trout Climate Assessment

Fish survey database
~10,000 sites

Historic Distributions

Future A1B Distributions

GCM

~50% reduction by 2080 under A1B

Habitat Response Curves

Species Vary in Climate Response

Predicted reduction (2080) =

- Cutthroat: 57%
- Brook: 77%
- Rainbow: 35%
- Brown: 48%

Context Matters: Spatial Variation in Habitat Loss

Rieman et al. 2007. TAFS 136:1552-1565
Westwide Gradient in Habitat Size & Resilience
Where should conservation resources be spent?

Pick me!

No, pick me!

No, pick me!

Pick me!
Where Can We Make a Difference?

Hydrologic Regime

Thermal Regime

20th Century

Population 1

21st Century

Lost Cause

Management Critical!

Resilient Population

Population 2

Population 3

Where Can We Make a Difference?

Modified from Williams et al. 2007
More Pressure, Fewer Resources

- Climate Change
- Urbanization & Population Growth
- Shrinking Budgets
- Need to do more with less
There’s A Lot on the Line

Climate Boogeyman

Recreational Fisheries

Low Flows Prompt Fishing Closure On Upper Beaverhead River And Reduced Limits On Clark Canyon Reservoir

Wednesday, September 29, 2004
Fishing

High Water Temperature In Grande

$4 - $30 Billion on Fish & Wildlife Recovery Efforts in PNW Since 1980

ESA Listed Species
Onus?  
Opportunity?  

Climate Boogeyman

Analytical Capacity
• Remote sensing/GIS
• Georeferenced, corporate databases
• Computational capacity
• Spatial models

More Collaboration

NOAA Fisheries  
IDAHÔ  
USGS  
Ronneville-Center for Ecosystems
US Forest Service  
TROUT UNLIMITED
Geospatial Tools for Accurate Regional Scale Stream Models

- Remote Sensing
- Visualization Tools
- GIS / Computing Capacity
- Climate, weather, GCM data availability
- Digital sensors

Nationally Consistent Hydrocoverages like USGS NHD+

Elevation

Distance

Slope

Drainage Area
Accurate, Spatially Consistent Information Needed Across Agencies

There’s an army of people doing stuff if it can be coordinated...
Maps Significantly Reduce Uncertainty

“Smart” Maps Can Be Developed from the Army’s Data

Geospatial technologies
NorWeST: A Regional Stream Temperature Database & Model for High-Resolution Climate Vulnerability Assessments

Dan Isaak, Seth Wenger¹, Erin Peterson², Jay Ver Hoef³ Charlie Luce, Steve Hostetler⁴, Jason Dunham⁴, Jeff Kershner⁴, Brett Roper, Dave Nagel, Dona Horan, Gwynne Chandler, Sharon Parkes, Sherry Wollrab

U.S. Forest Service
¹Trout Unlimited
²CSIRO
³NOAA
⁴USGS

Thank [image of fish and water]

Team consists of 15 people…scientists, database most important & managers since it's all your data we're working with

Mention R1 support, Jason support to give R6 sense & others of $
Previous Trout Climatic Assessments

No stream temperature component

Air Temperatures...

- Meisner 1988, 1990
- Eaton & Schaller 1996
- Keleher & Rahel 1996
- 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.
Air Temp ≠ Stream Temp

$\text{r}^2 = 0.26$

PRISM Air Temperature (°C)

Stream Temperature (°C)

Complex topography

Glaciation

Groundwater buffering

Riparian differences
Lots of Temperature Data Out There...

Stealth Sensor Network
>45,000,000 hourly records
>15,000 unique stream sites

>60 agency contributors
~$10,000,000 database value
Regional Temperature Model

Accurate temperature models

Cross-jurisdictional “maps” of stream temperatures

Consistent datum for strategic assessments across 350,000 stream kilometers

y = 0.68x + 3.82

y = 0.55x + 7.79

y = 0.86x + 2.43

y = 0.93x + 0.830

Predicted (°C)

Observed (°C)

Replace with validation Data from 2007
Example: Salmon River Basin

Data extracted from NorWeST

- 21,000 stream kilometers
- 4,401 August means
- 1,737 stream sites
- 19 climate summers
- Temperature site
- 67% data from USFS
Salmon River Temperature Model

\[ n = 4,401 \]

Covariate Predictors

1. Elevation (m)
2. Canopy (%)
3. Stream slope (%)
4. Ave Precipitation (mm)
5. Latitude (km)
6. Lakes upstream (%)
7. Baseflow Index
8. Watershed size (km$^2$)
9. Discharge (m$^3$/s)
   - USGS gage data
10. Air Temperature (°C)
    - RegCM3 NCEP reanalysis
    - Hostetler et al. 2011

Mean August Temperature

\[ r^2 = 0.89; \text{ RMSE} = 0.86^\circ\text{C} \]
Models Enable Climate Scenario Maps

Many possibilities exist...

Adjust air & discharge values to represent scenarios.
Historic Scenario: Salmon River (S2_02-11)
2002-2011 mean August stream temperatures

1 kilometer resolution
21,000 stream km
Translate Stream Temperature Maps to Thermally Suitable Habitats

Stream temperature maps

Regional fish survey databases (n = 10,000)

Occurrence probability

Temperature (°C)

Wenger et al. 2011b. *CJFAS* **68**:988-1008; Wenger et al., *In Preparation*
Generalizable to All Stream Biotas

There will be other vulnerable species besides trout

Too warm...Too cold...Just right
Salmon River Bull Trout Habitats

2002-2011 Historical

11.2 °C isotherm

Suitable
Unsuitable
Salmon River Bull Trout Habitats

+1°C Stream Temperature

11.2 °C isotherm

Suitable

Unsuitable
Salmon River Bull Trout Habitats

+2°C Stream Temperature

11.2 °C isotherm

Suitable

Unsuitable
Spatial Variation in Habitat Loss

2002-2011 historical scenario

11.2 °C isotherm
Spatial Variation in Habitat Loss

+1°C stream temperature scenario

11.2 °C isotherm

Velocity Kills...

EFK. Salmon

White Clouds

11.2 °C isotherm
Climate Velocity is How Fast Isotherms Shift Across the Earth’s Surface

Climate Velocity Map for River Network

Mainstem Fisheries Will See First & Most Pronounced Thermal Impacts

Low Flows Prompt Fishing Closure On Upper Beaverhead River And Reduced Limits On Clark Canyon Reservoir

Wednesday, September 29, 2004
Fishing

denverpost.com
FISHING
Heat causing fishing closures

July 3, 2012

High Water Temperature In Grande Ronde Kills 239 Adult Spring Chinook
Columbia Basin Bulletin, August 14, 2009 (PST)
Topography & Climate Vulnerability

Slow climate velocities

Elevational Refuges

Fast climate velocities

Latitudinal Refuges
Spatial Variation in Habitat Loss

2002-2011 historical scenario

11.2 °C isotherm
Spatial Variation in Habitat Loss

+1°C stream temperature scenario

11.2 °C isotherm
Difference Map Shows Vulnerable Habitats
+1°C stream temperature scenario

Where to invest?

11.2 °C isotherm
Strategic Prioritization of Restoration Actions is Possible

• Maintaining/restoring flow...
• Maintaining/restoring riparian...
• Restoring channel form/function...
• Prescribed burns limit wildfire risks...
• Non-native species control...
• Improve/impede fish passage...

Work here? or here?
Integrate with...

Watershed Condition Indicators

Forest Plan Revisions

Proposed Land Management Plan
Clearwater National Forest
NorWeST is a “Crowd-Sourced” Model Developed from Everyone’s Data

Data Collected by Local Bios & Hydros

Coordinated, Interagency Responses?

Management Actions
NorWeST Website Distributes Scenarios & Other Temperature Products as GIS Layers

1) GIS shapefiles of stream temperature scenarios

2) GIS shapefiles of stream temperature model prediction precision

3) Temperature data summaries

Google “NorWeST” or go here...

http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.shtml
NorWeST Facilitating Related Projects

• Regional bull trout climate vulnerability assessment (J. Dunham)
• Cutthroat & bull trout climate decision support tools (Peterson et al., 2013)
• Landscape-scale bull trout monitoring protocol (Isaak et al. 2009)
• Consistent thermal niche definitions & more accurate bioclimatic models for trout & nongame fishes (S. Wenger, R. Al-Chokhachy, In Prep.)
• Efficient stream temperature monitoring designs
NorWeST Facilitating Related Projects

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“Apps” Run on a Consistent Data Network
Real-time Access to Stream Spatial Data Anytime, Anywhere

Smartphones as field computers

ArcGIS app

Temperature Maps

Prediction Precision Maps

Habitat Maps

GoogleMaps
An InterNet for Stream Data

GIS infrastructure now exists...

Spatial models

1G LCC
Accurate & consistent scaling of information

55 National Forests
350,000 stream kilometers
Significant Unknowns:
Where Do We Level Off (+1°C, +3°C, etc.) & When Do We Get There?

IPCC 2007
Significant Unknowns:
Is it Going to Get Wetter or Dryer?

Precipitation trends (1950-2009)

Past may not be a prelude in this case...

U.S. Climate Change Science Program. 2009
Precipitation Declines = Habitat Reductions & Fragmentation
Significant Unknowns:

How Fast Are Fish Distributions Shifting?

Average distribution shift across taxa =

6.1 km/decade poleward OR
6.1 m/decade higher

### Significant Unknowns:

**How Much Habitat is Needed to Persist?**

<table>
<thead>
<tr>
<th>Occurrence</th>
<th>Watershed area (ha)</th>
<th>Stream length (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>p &gt; 0.5</td>
<td>~3,000</td>
<td>~13</td>
</tr>
<tr>
<td>p &gt; 0.9</td>
<td>~10,000</td>
<td>~40</td>
</tr>
</tbody>
</table>

Rieman & McIntyre 1995
Isaak et al. 2010

![Graph showing Bull trout occurrence versus habitat patch size](image)

Significant Unknowns:

- Habitat patch size (ha)
  - Bull trout occurrence
  - Occupied Patch
  - Unoccupied Patch

Map showing occupied and unoccupied patches.
Extremes May Become More Extreme...

http://www.ncdc.noaa.gov/extremes/cei/graph/1c/ytd
Number of Climatic “Events” May Increase Dramatically
More & Bigger Wildfires

Fires > 10,000 Acres on USFS Lands

If +1.0 °C...

National Research Council 2011
Dynamic Equilibrium

Can We Adjust Our Mindsets?

Dynamic Dis-Equilibrium

Significant Unknowns:
Can we Make Hard Choices & Let Some Populations Go?

Resilient Populations

Lost Cause

Sorry Charlie
Do We Need Fish Conservation Reserves?

Native Fish Conservation Areas: A Vision for Large-Scale Conservation of Native Fish Communities

Jack E. Williams, Richard N. Williams, Russell E. Thurow, Leah Elwell, David P. Philipp, Fred A. Harris, Jeffrey L. Kershner, Patrick J. Martinez, Dirk Miller, Gordon H. Reeves, Christopher A. Frissell, and James R. Sedell

Where Should these Be? & Which Species?
The Sooner We Act, The Bigger The Impact
Climate-Aquatics Syntheses...

**Three Questions:**

1) **What is changing** in the climate and related physical processes that may influence aquatic species and their habitats?

2) **What are the implications** for fish populations, aquatic communities and related conservation values?

3) **What can we do about it?**

Rieman & Isaak 2010.

Need to Do More With Less, but What If... We Did Much More?

Climate Change

Urbanization & Population Growth

Shrinking Budgets

Mighty Mouse

Fish Biologist

Here I come to save the day!
Connect the Dots to Map the Future & the People & the Agencies

- Climate Change
- Urbanization & Population Growth
- Land & Species Management