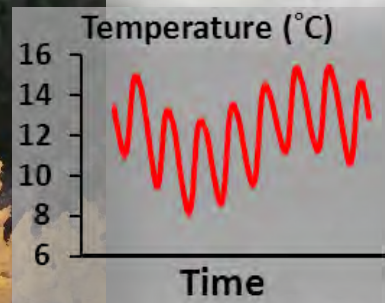
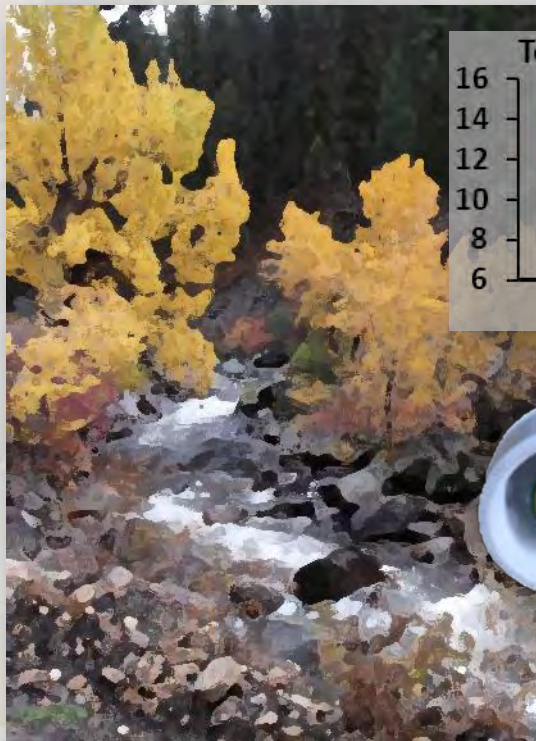
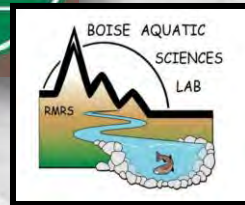


# Rapid Emergence of Massive Temperature Monitoring Networks in Streams & Rivers Across North America

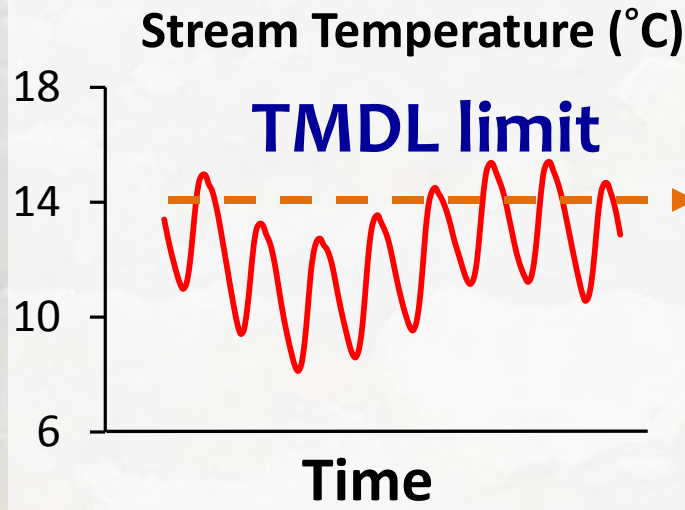
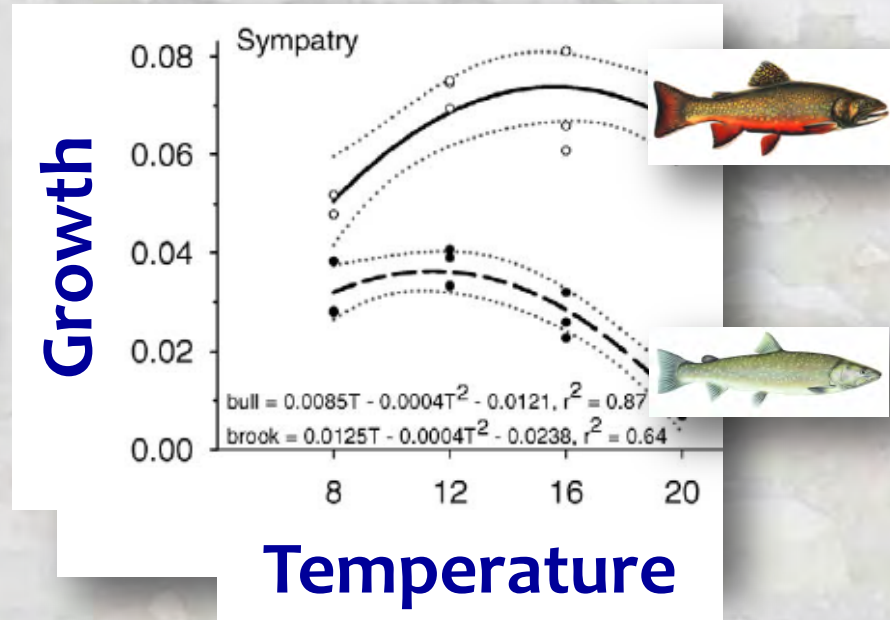
Dan Isaak, US Forest Service

Rocky Mountain Research Station





# Temperature TMDL Standards & Effects on Aquatic Organisms



**Too Hot!**



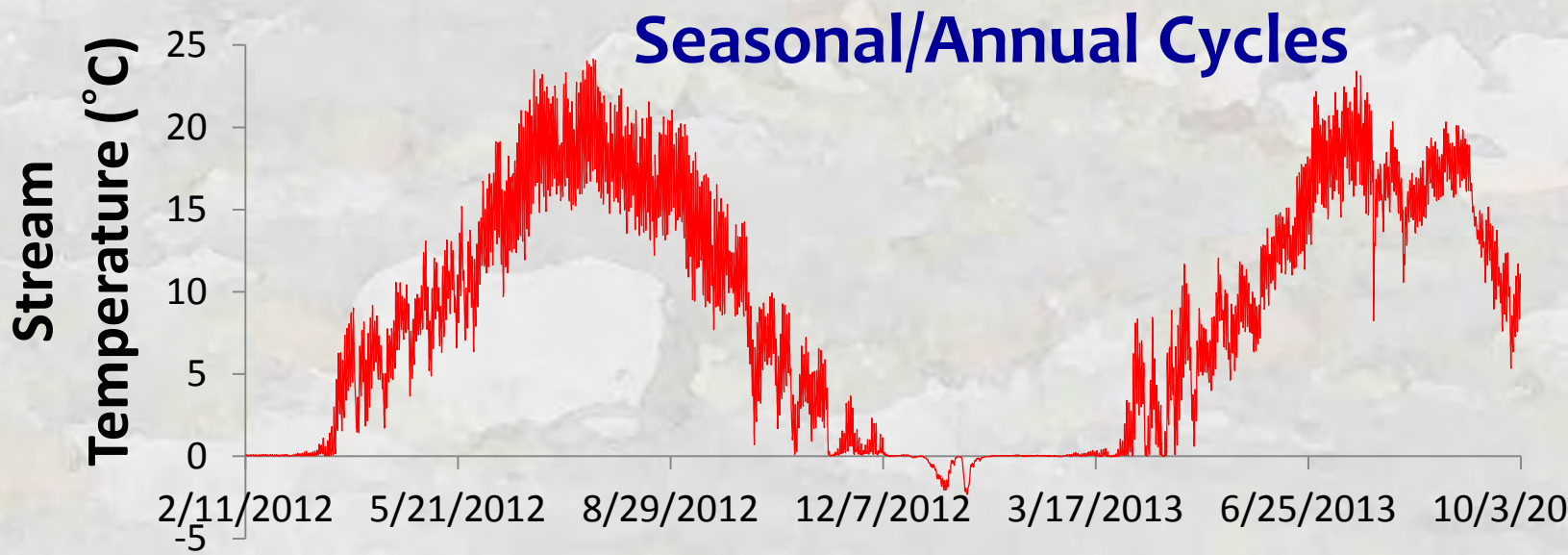
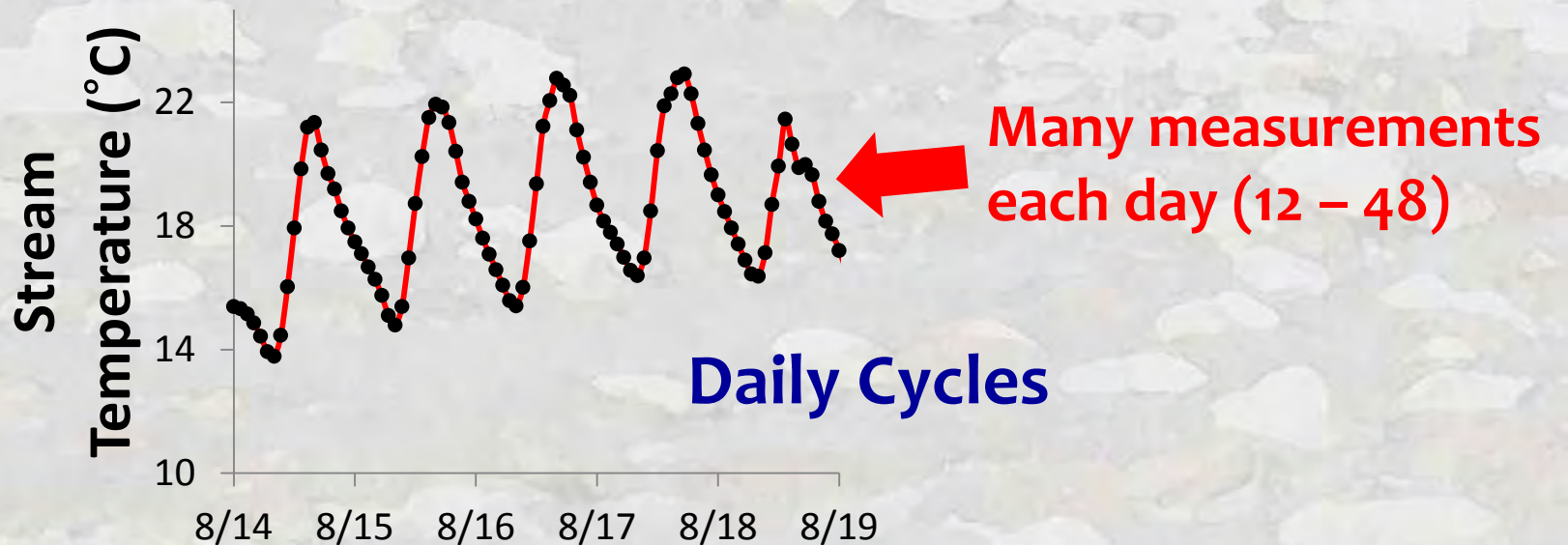
# Miniature Temperature Sensors



Sensor model	Accuracy	Battery life & memory	Cost
Hobo Pro v2	+/-0.2°C	6 years	\$123
Tidbit v2	+/-0.2°C	5 years	\$133
iButton	+/-0.5°C	1 year	\$20 – 40
Tinytag Aquatic 2	+/-0.5°C	1 year	\$170



# Continuous Temperature Record from Each Sensor



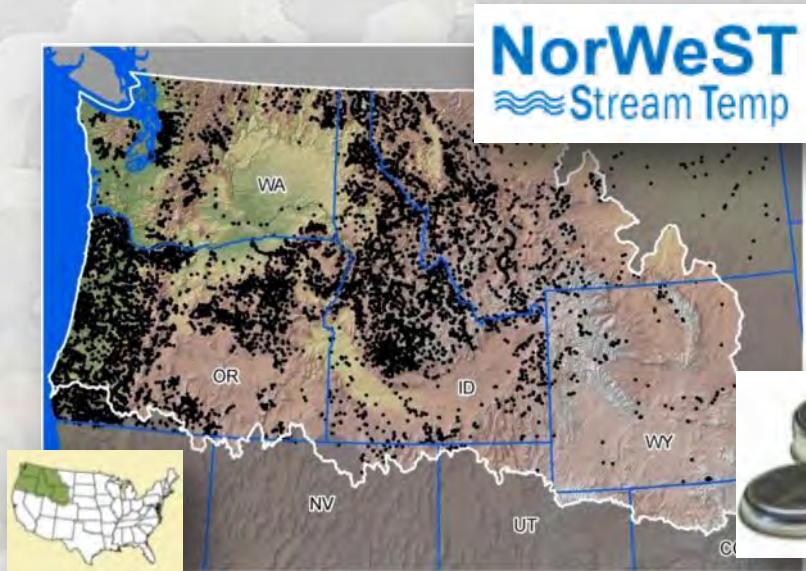


# Temperature Data Collection is Ubiquitous





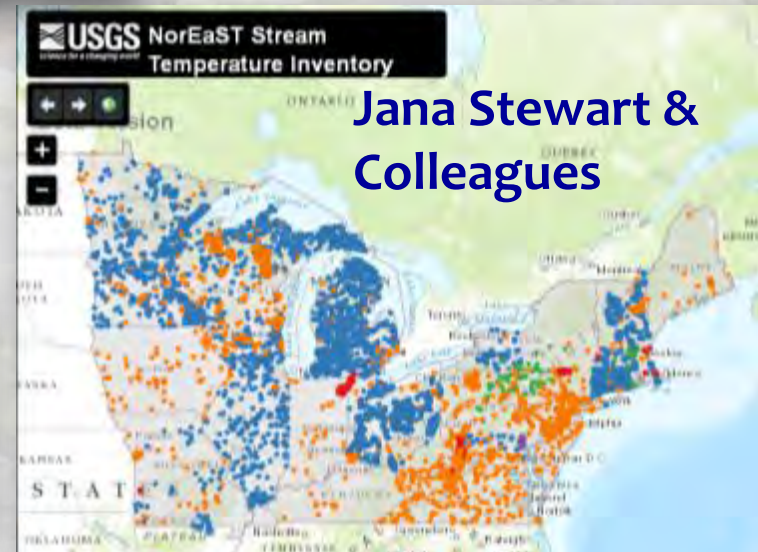
# Regional Database Aggregation Projects Are Underway



**Free  
millions!**

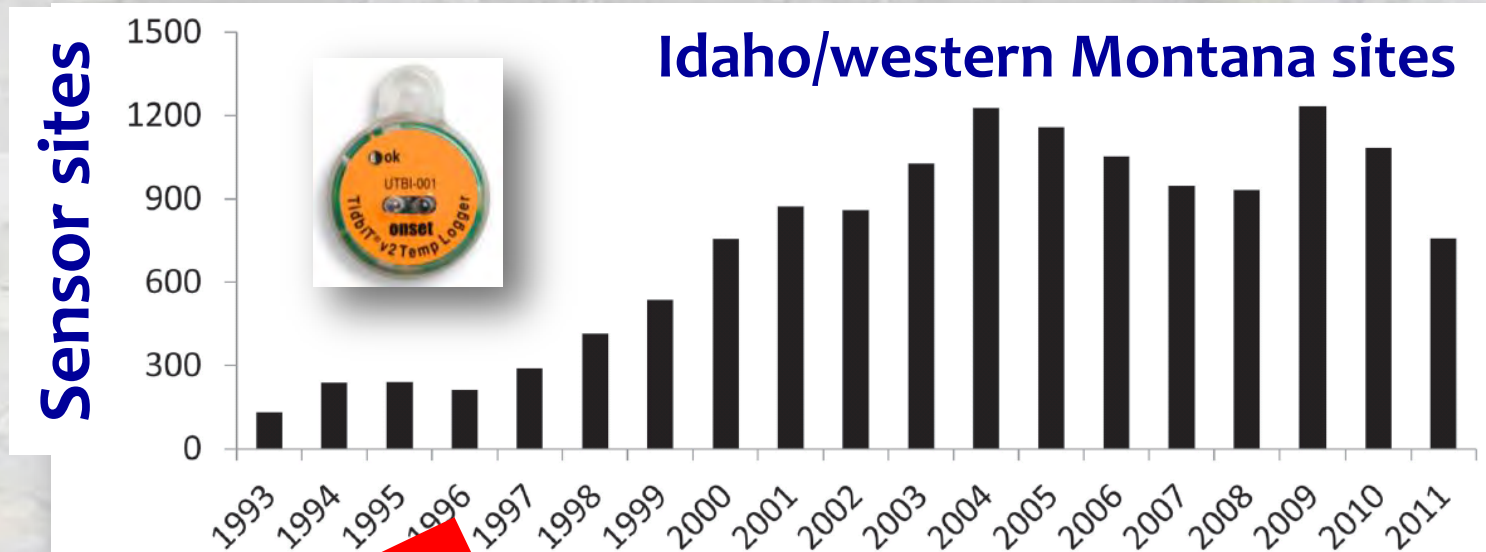


**>60 agencies  
>45,000,000 hourly records  
>15,000 unique sites**

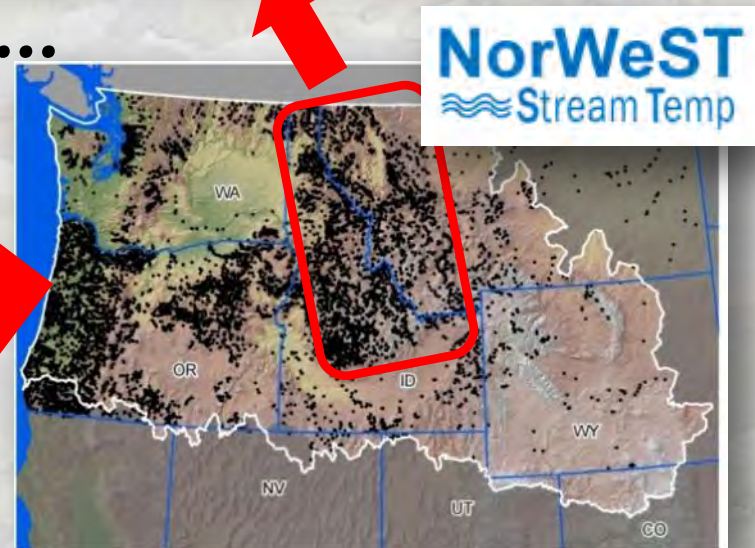
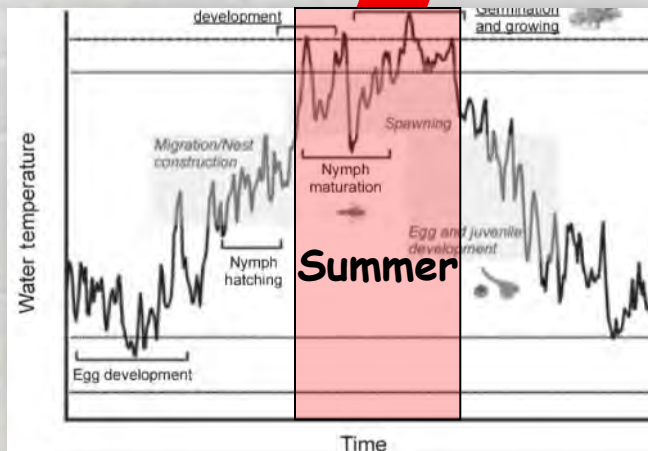




# We Monitor Lots of Sites,

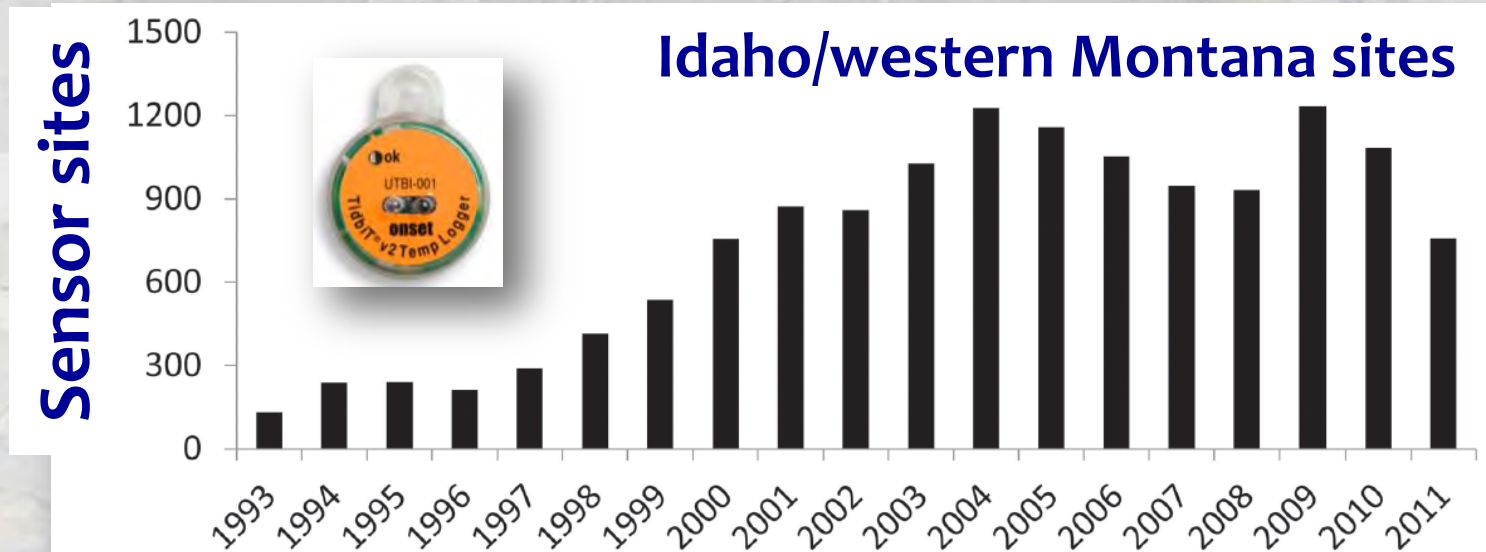


but only in the summer & ...

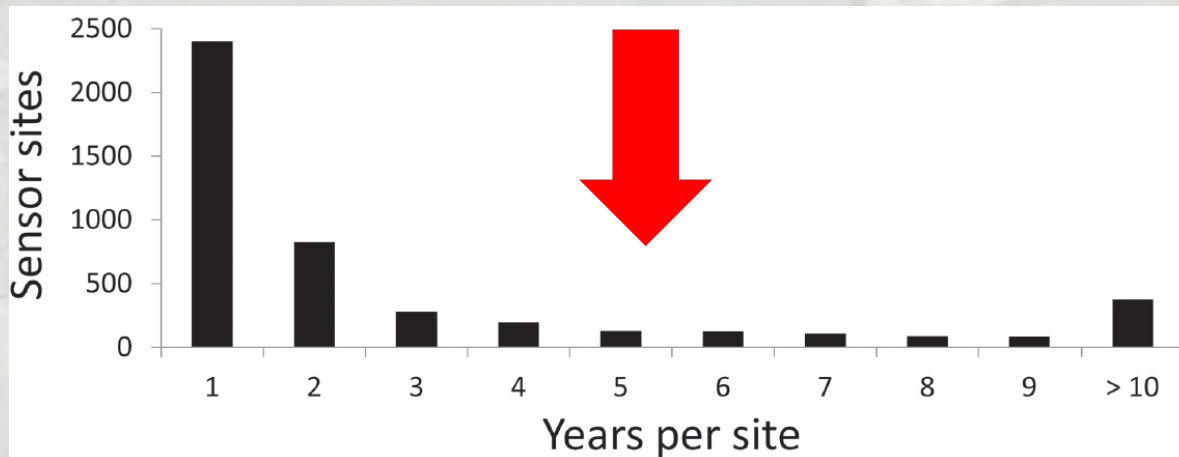


Isaak et al. 2013. A simple protocol using underwater epoxy to install annual temperature monitoring sites in rivers and streams. USFS General Technical Report, 314.

# We Monitor Lots of Sites,



**& not for very long**



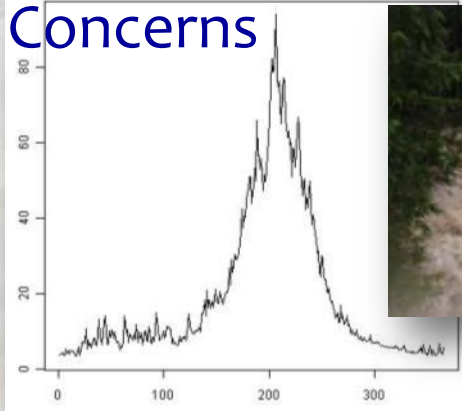
Isaak et al. 2013. A simple protocol using underwater epoxy to install annual temperature monitoring sites in rivers and streams. USFS General Technical Report, 314.



# Epoxy Protocol for Annual Monitoring

Annual Flooding

Concerns



Underwater epoxy cement



\$130 = 5 years of data

Data retrieved  
from underwater



Sensors glued to large  
boulders & bridges



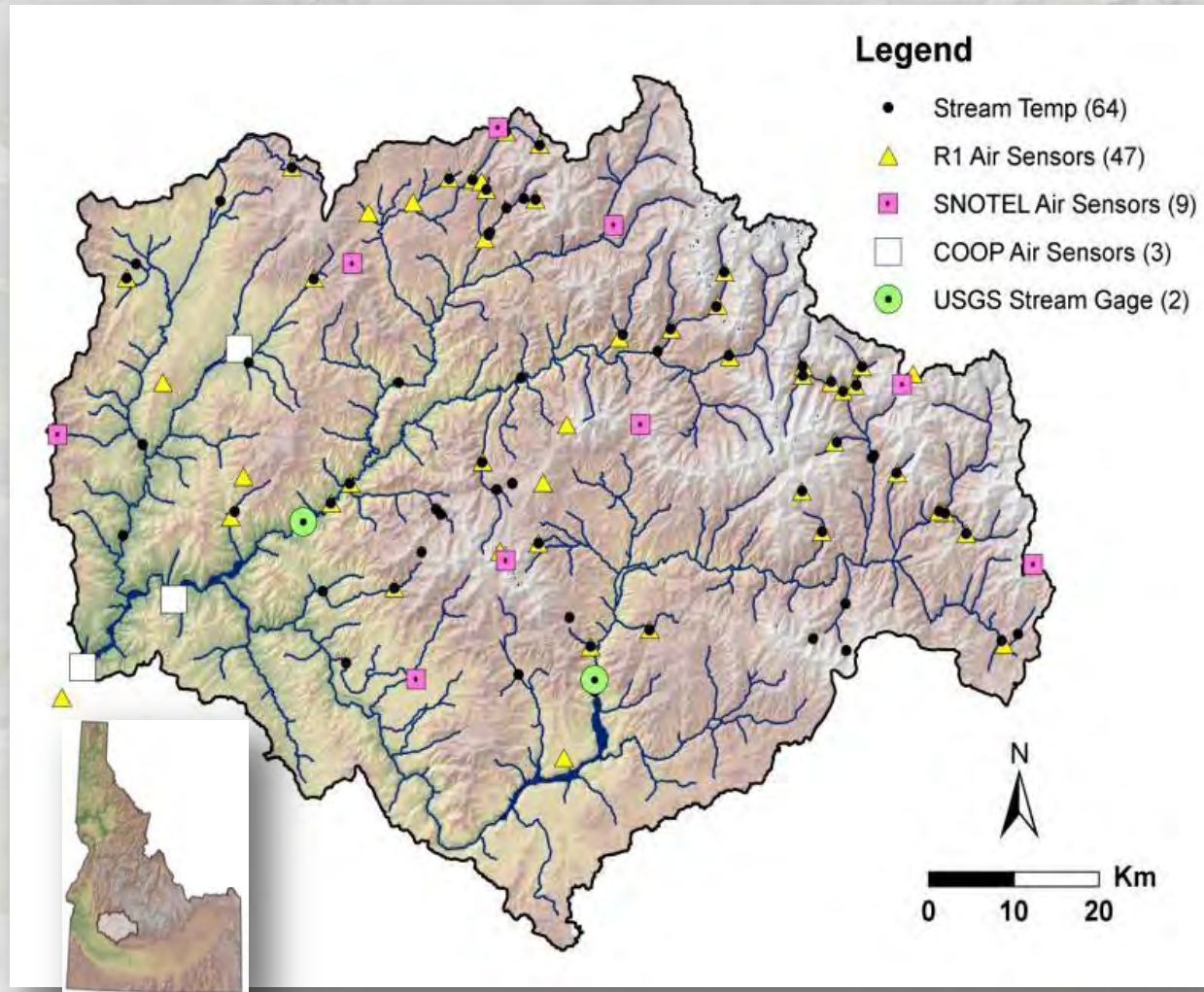
Isaak et al. 2013. USFS Report;  
Isaak & Horan 2011. *NAJFM* 31:134-137



# Example Monitoring Networks...

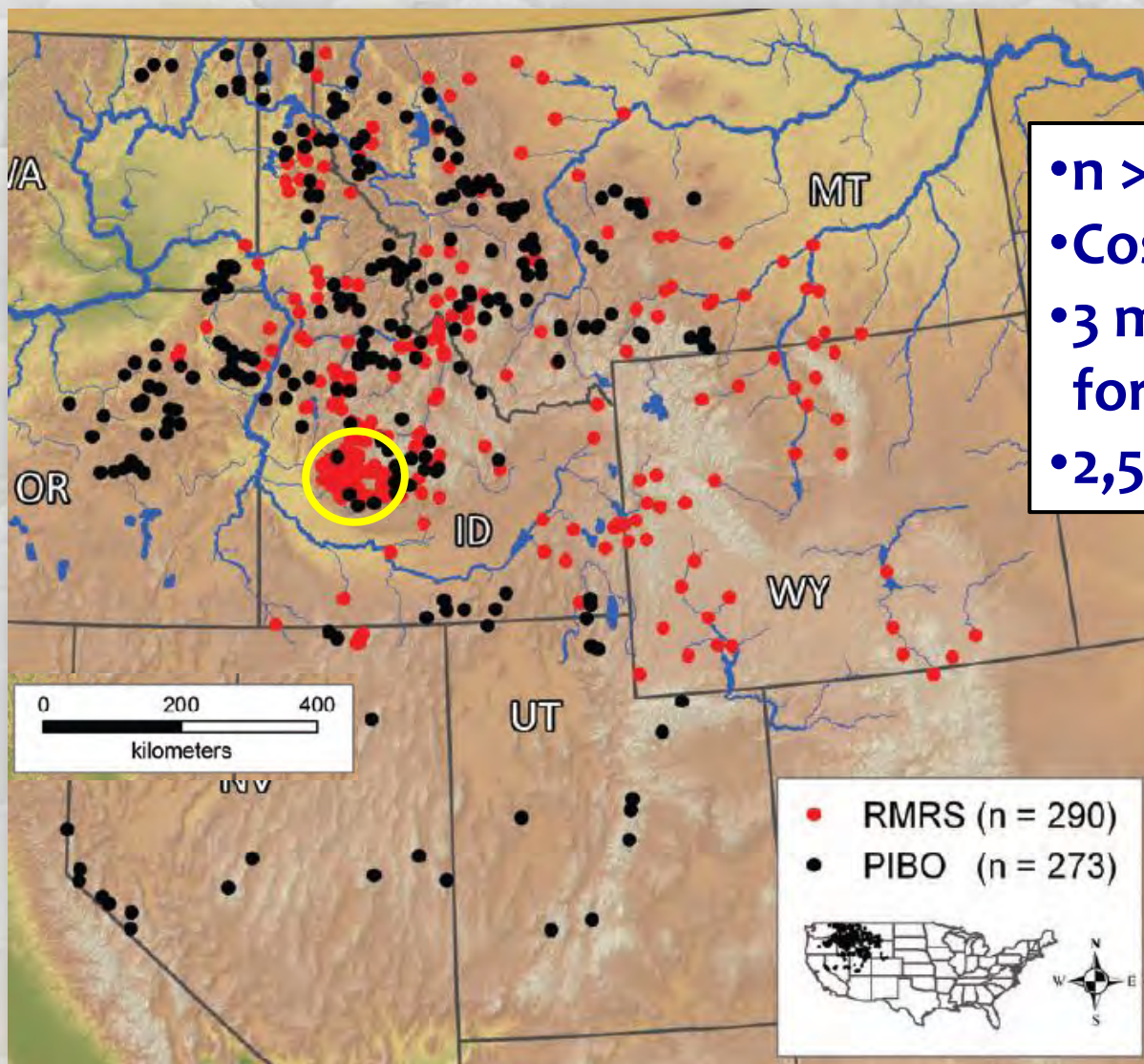
## Dense sensor arrays for landscape analysis

Boise River Basin – 7,000 hectares

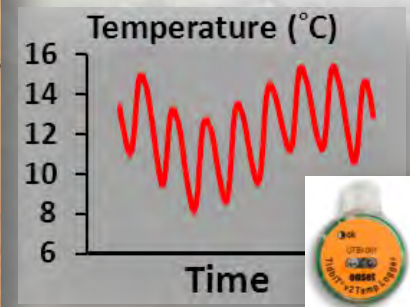




# NoRRTN: Northern Rockies River Temperature Network



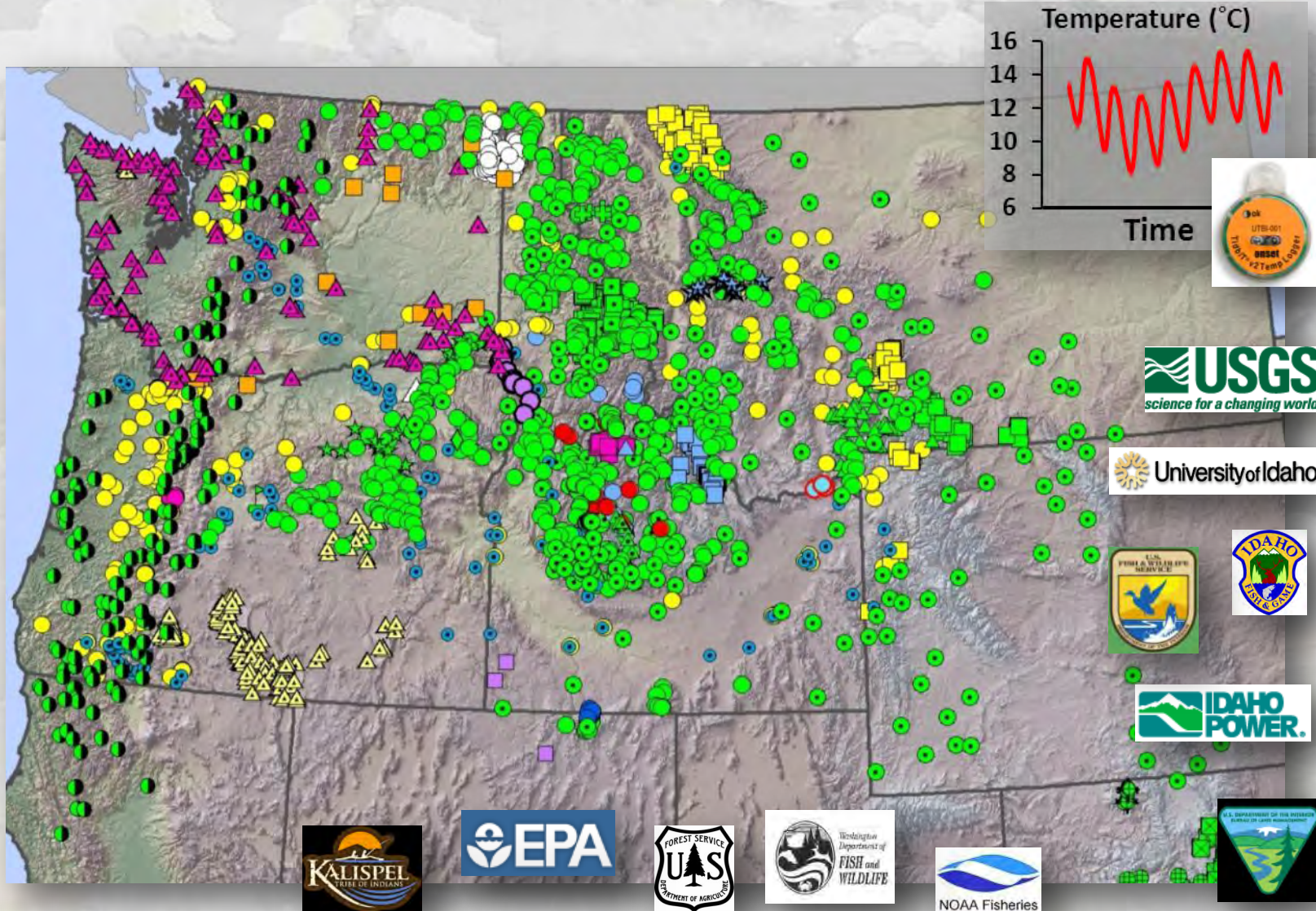
- n > 500 sites;
- Cost = \$100,000;
- 3 months time for 2 technicians;
- 2,500 years data





# Interagency Monitoring Networks

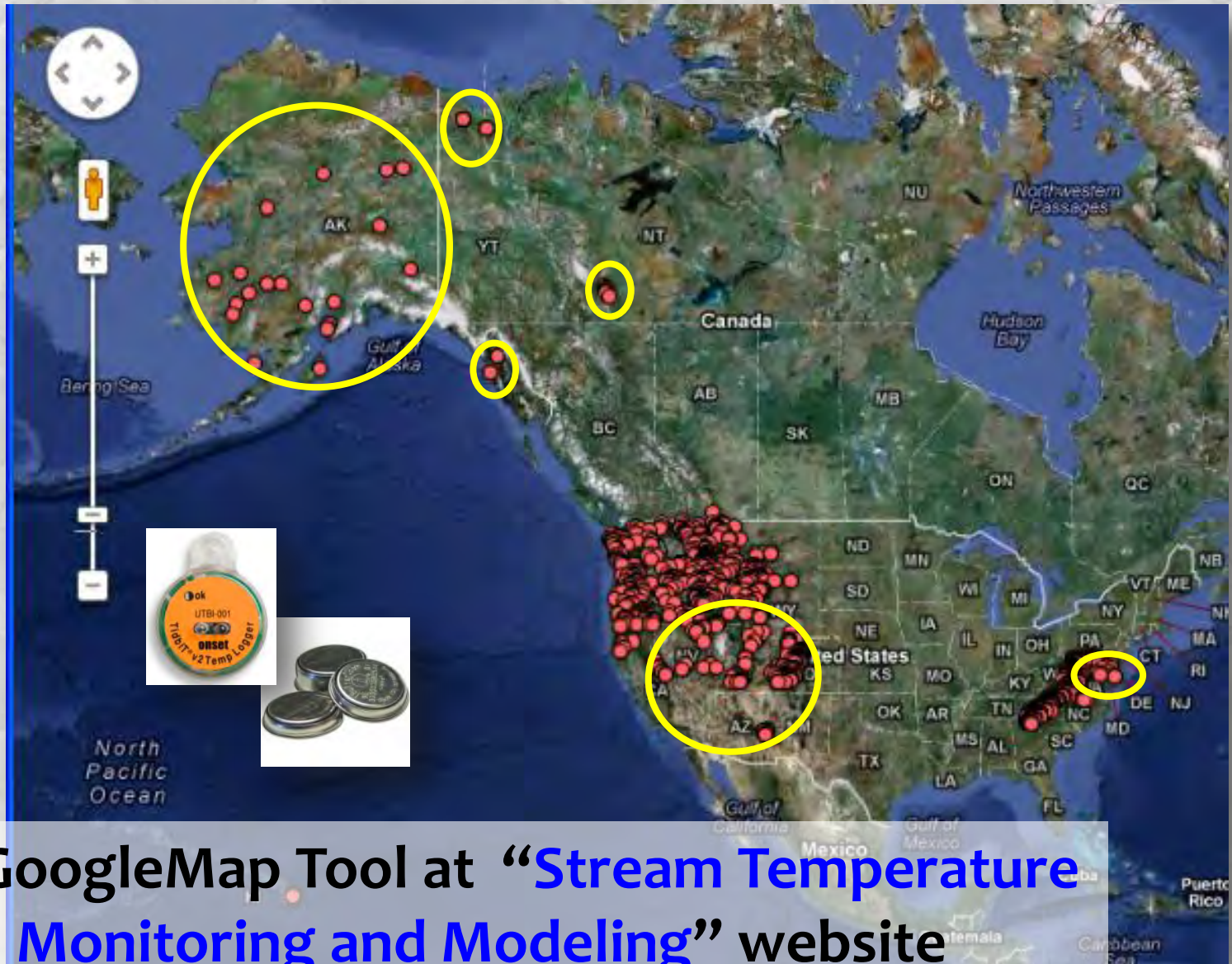
>3,000 sites in Northwest U.S.





# Continental Network is Emerging

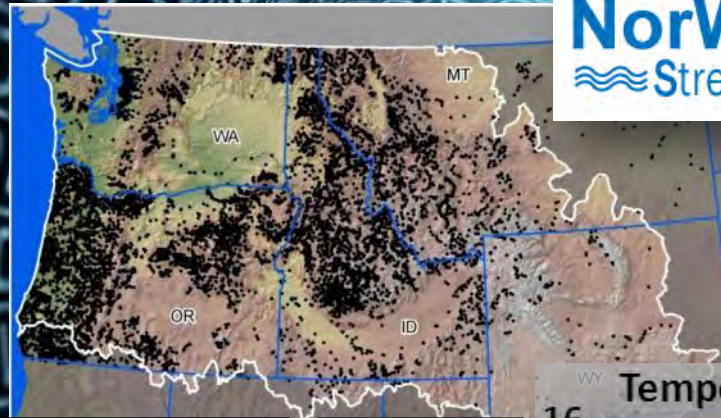
>500 new sites last year



GoogleMap Tool at “Stream Temperature Monitoring and Modeling” website

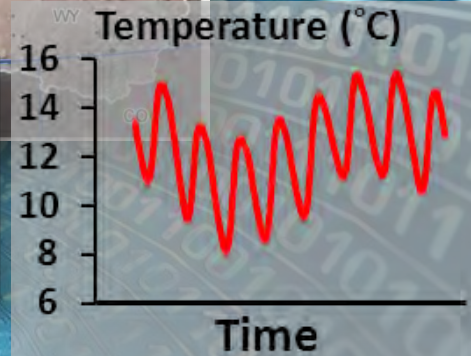


# BIG DATA = BIG INFORMATION?



**NorWeST**  
Stream Temp

**~45,000,000  
hourly records**



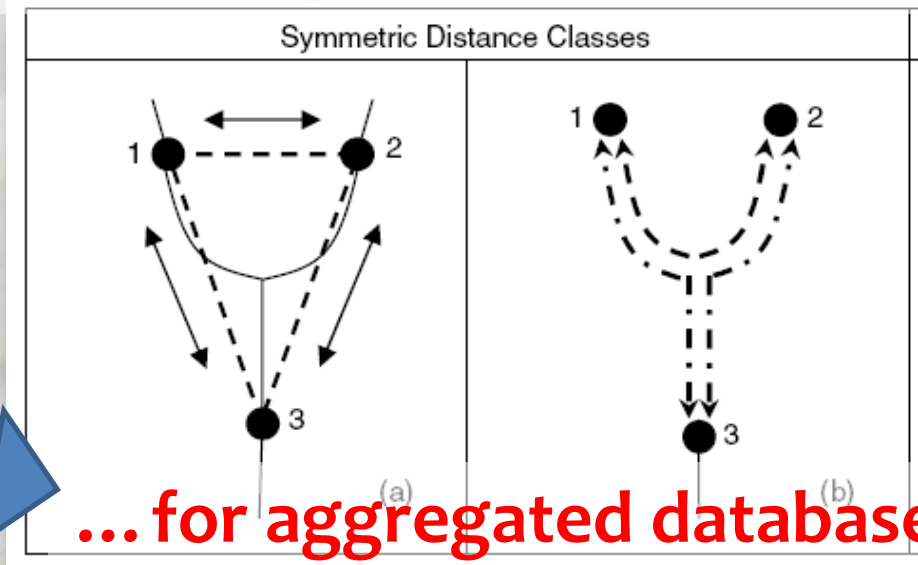


# BIG DATA are often Autocorrelated

## Spatial Statistical Network Models



**Valid interpolation on networks**

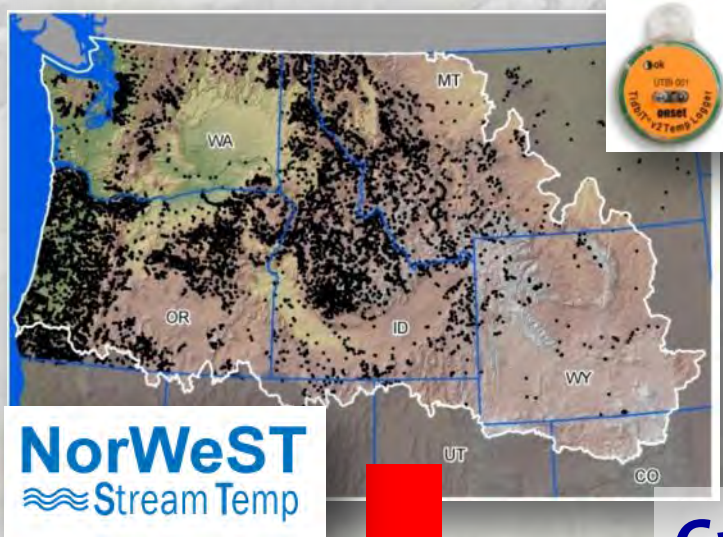


**Advantages:**

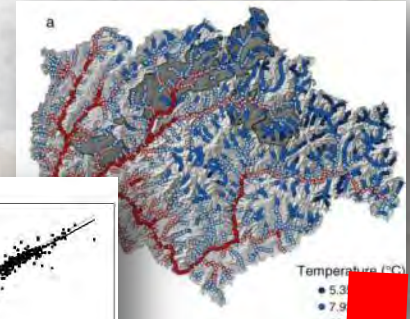
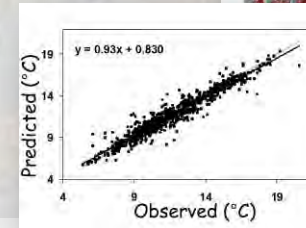
- flexible & valid autocovariance structures that accommodate network topology & non-independence among observations
- improved predictive ability & parameter estimates relative to non-spatial models



# Regional Temperature Model

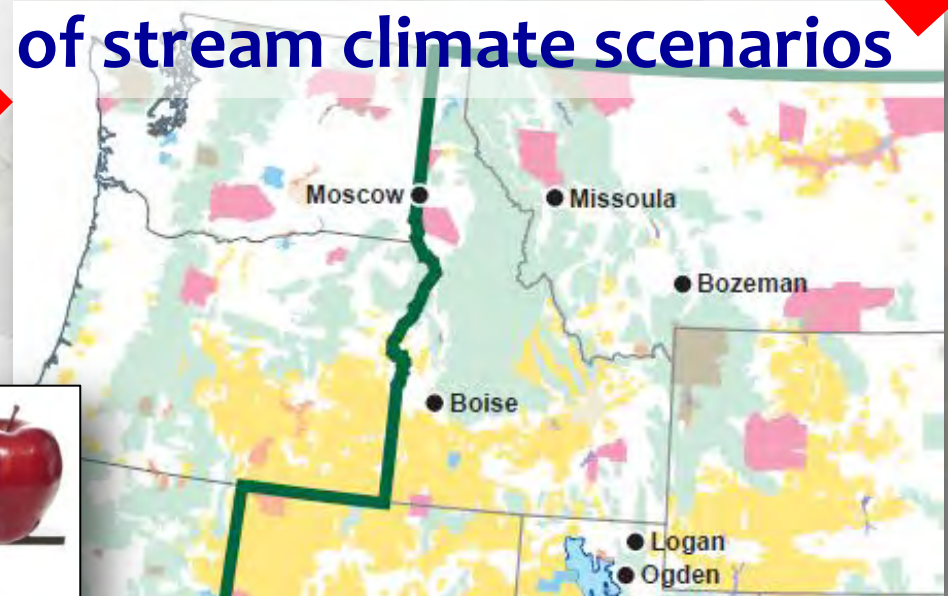
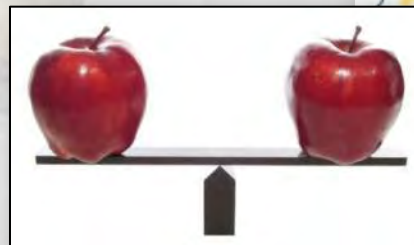


Accurate stream temp  
model



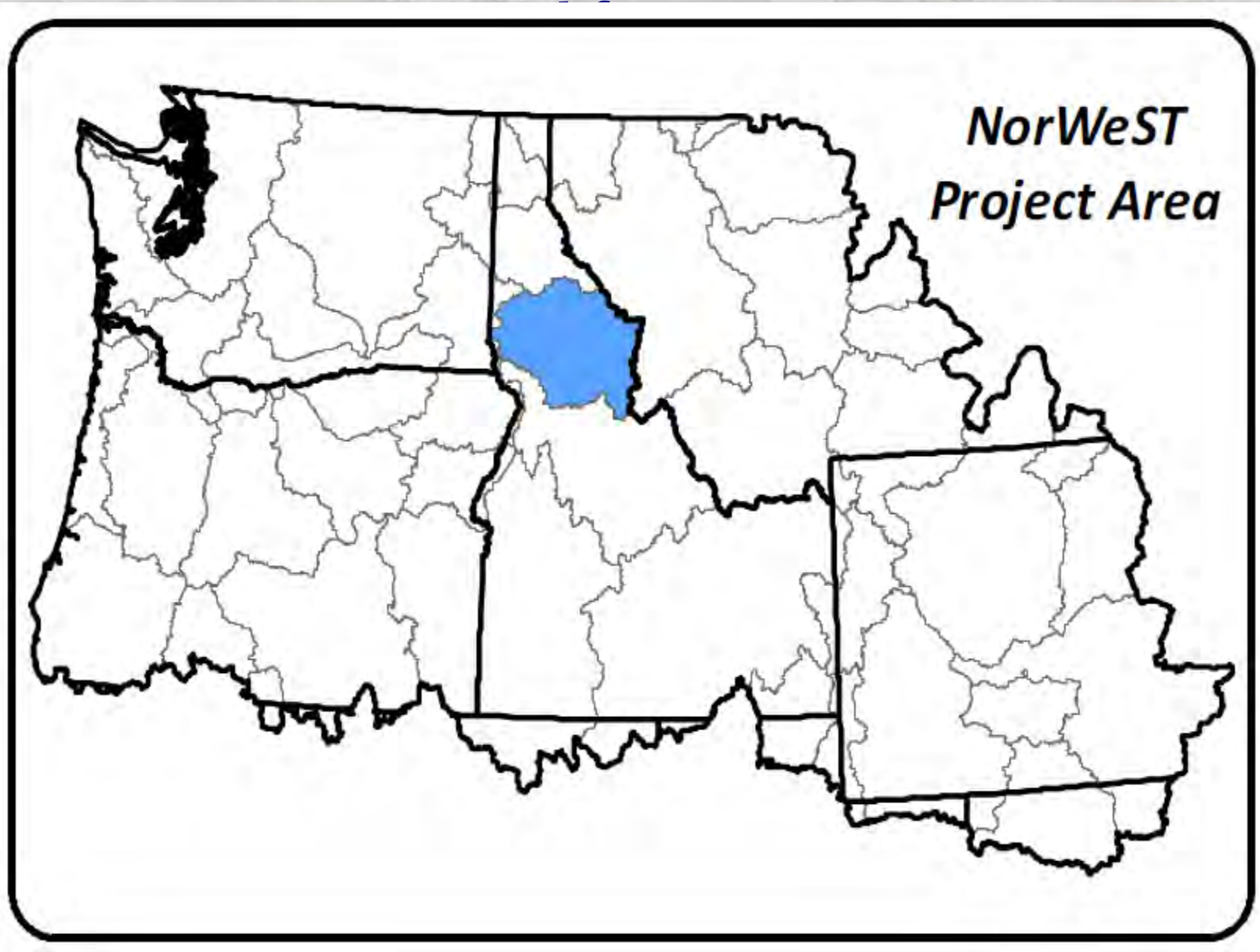
Cross-jurisdictional “maps”  
of stream climate scenarios

Consistent datum for  
strategic assessments  
across 500,000 stream  
kilometers





# Example: Clearwater River Basin



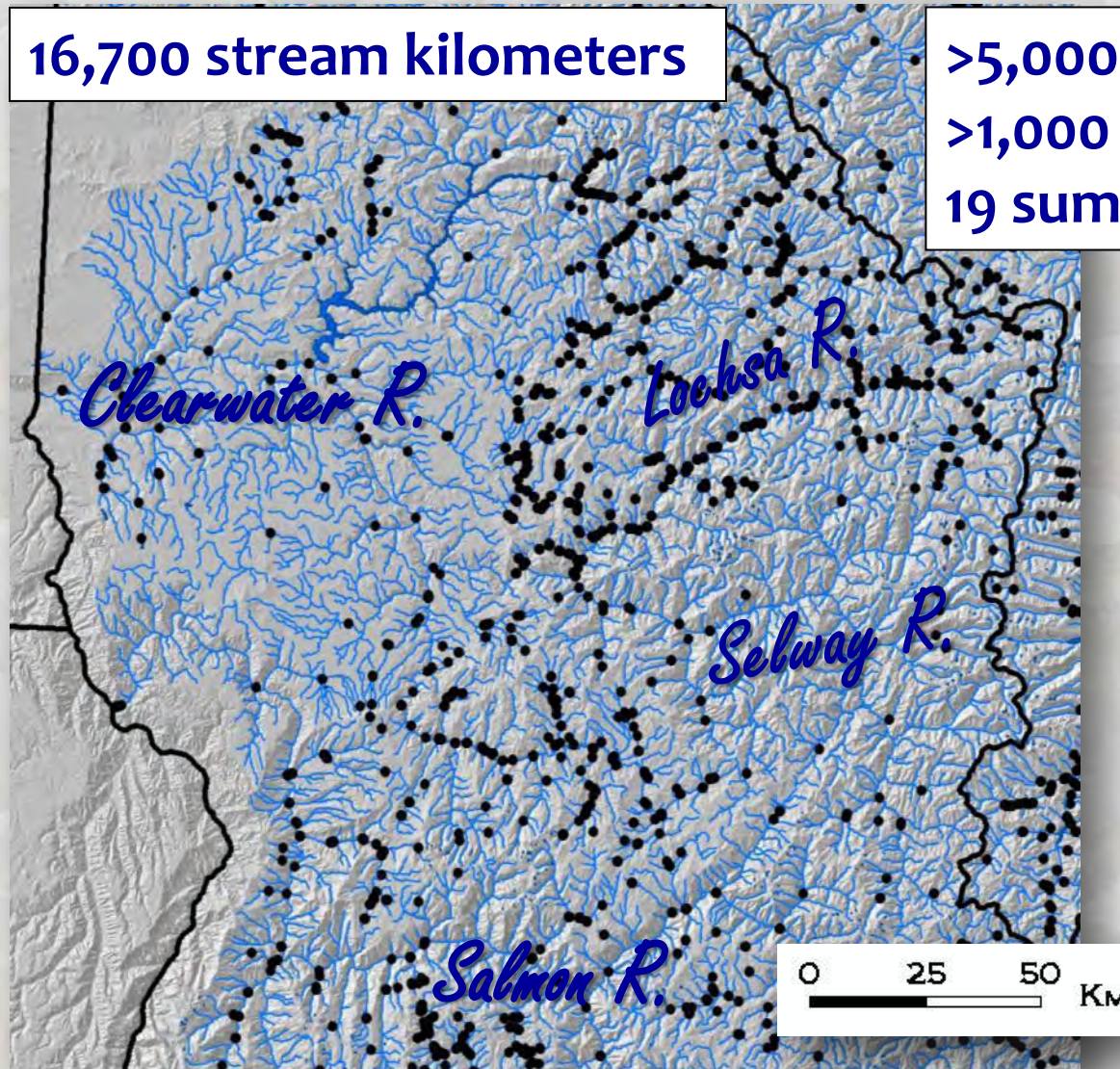


# Example: Clearwater River Basin

## Data extracted from NorWeST

16,700 stream kilometers

>5,000 August means  
>1,000 stream sites  
19 summers (1993-2011)



•Temperature site



# Clearwater River Temp Model

**n = 4,487**

**Mean August Temperature**

## 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<sup>2</sup>)

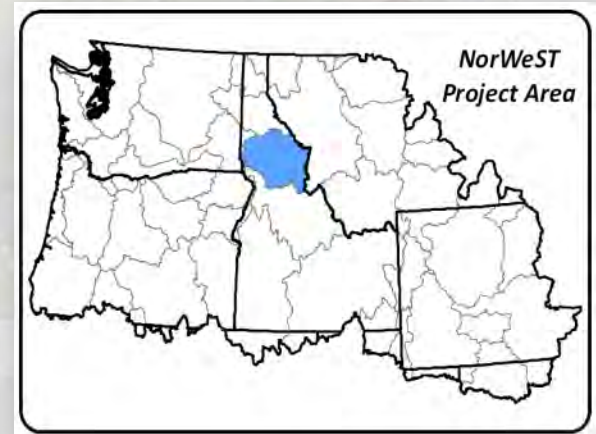
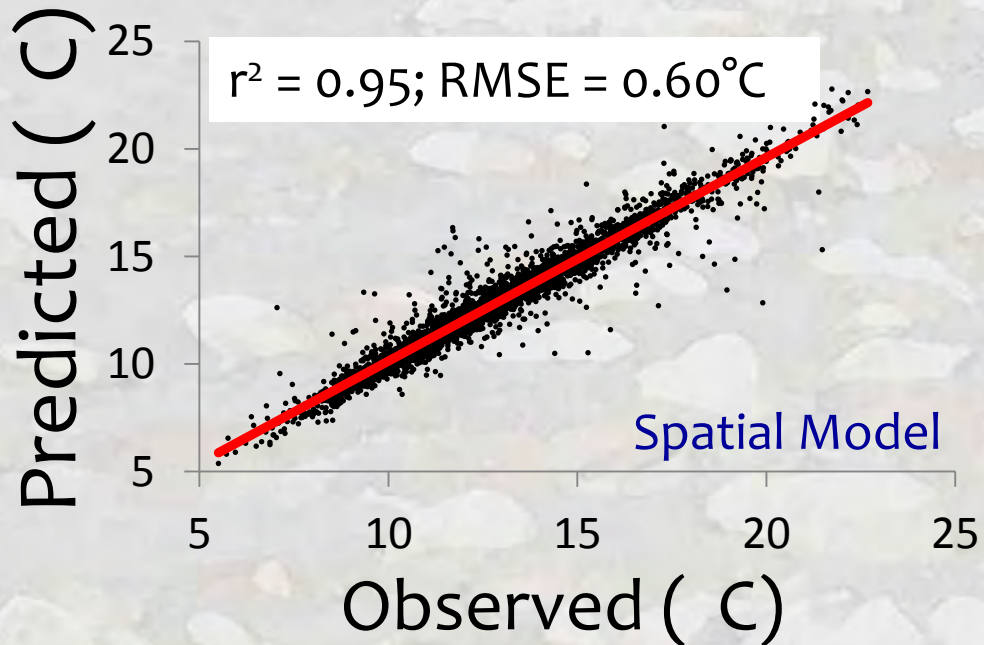
9. Discharge (m<sup>3</sup>/s)

**USGS gage data**

10. Air Temperature (°C)

**RegCM3 NCEP reanalysis**

**Hostetler et al. 2011**

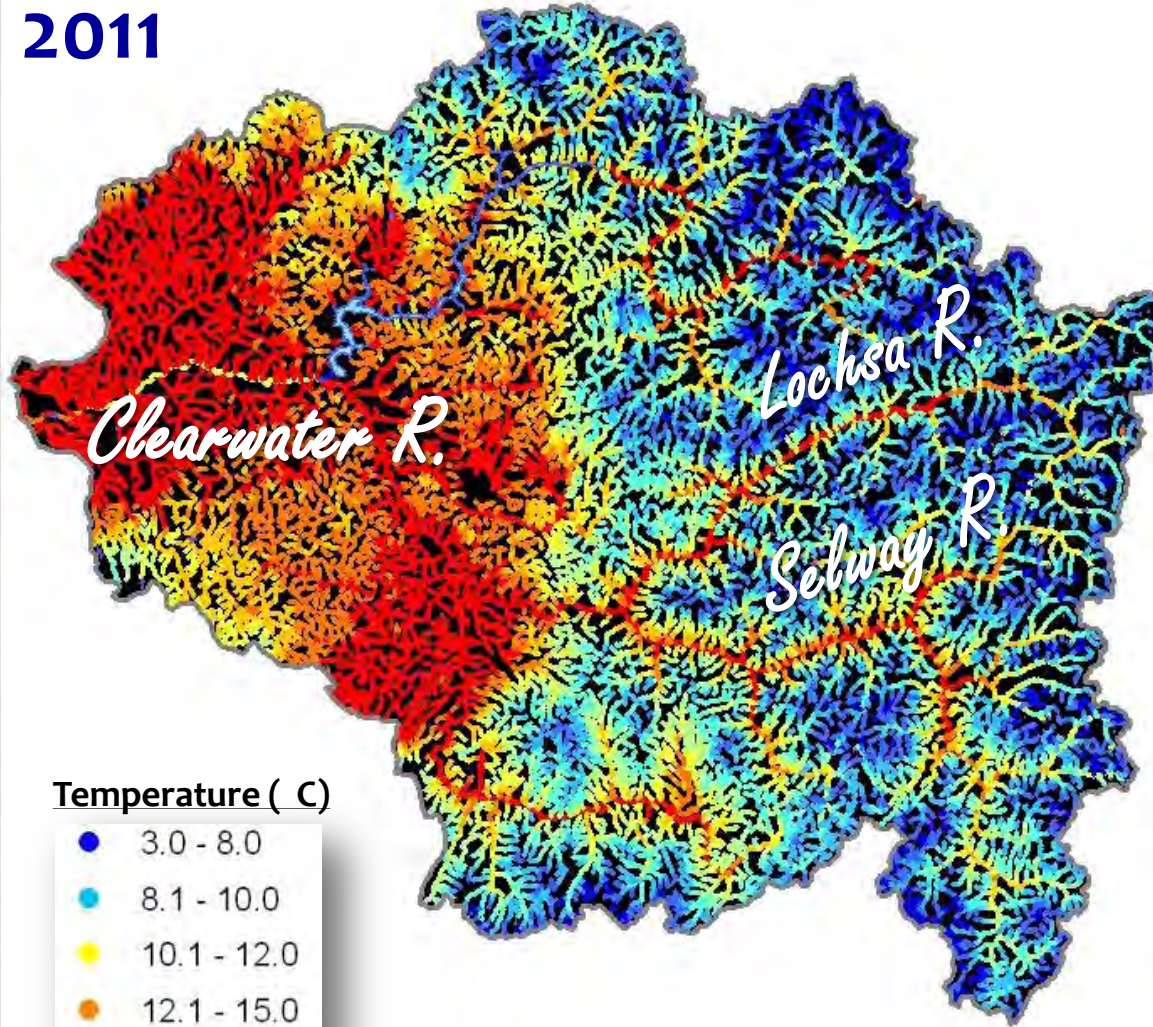




# Historical Year Sequence (1993-2011)

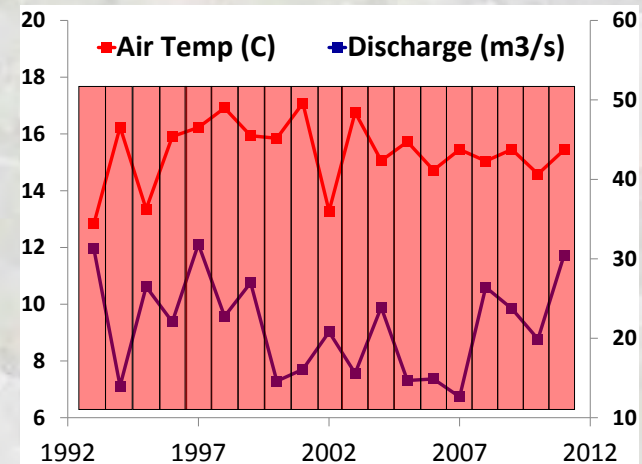
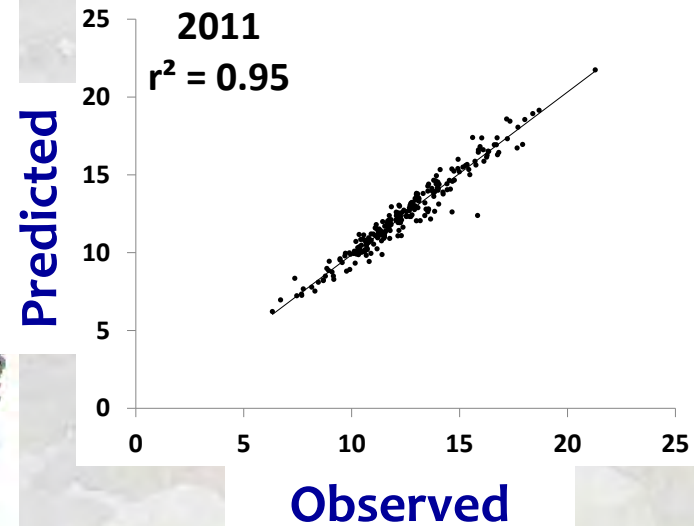
## Mean August Temperature - Clearwater Basin

2011



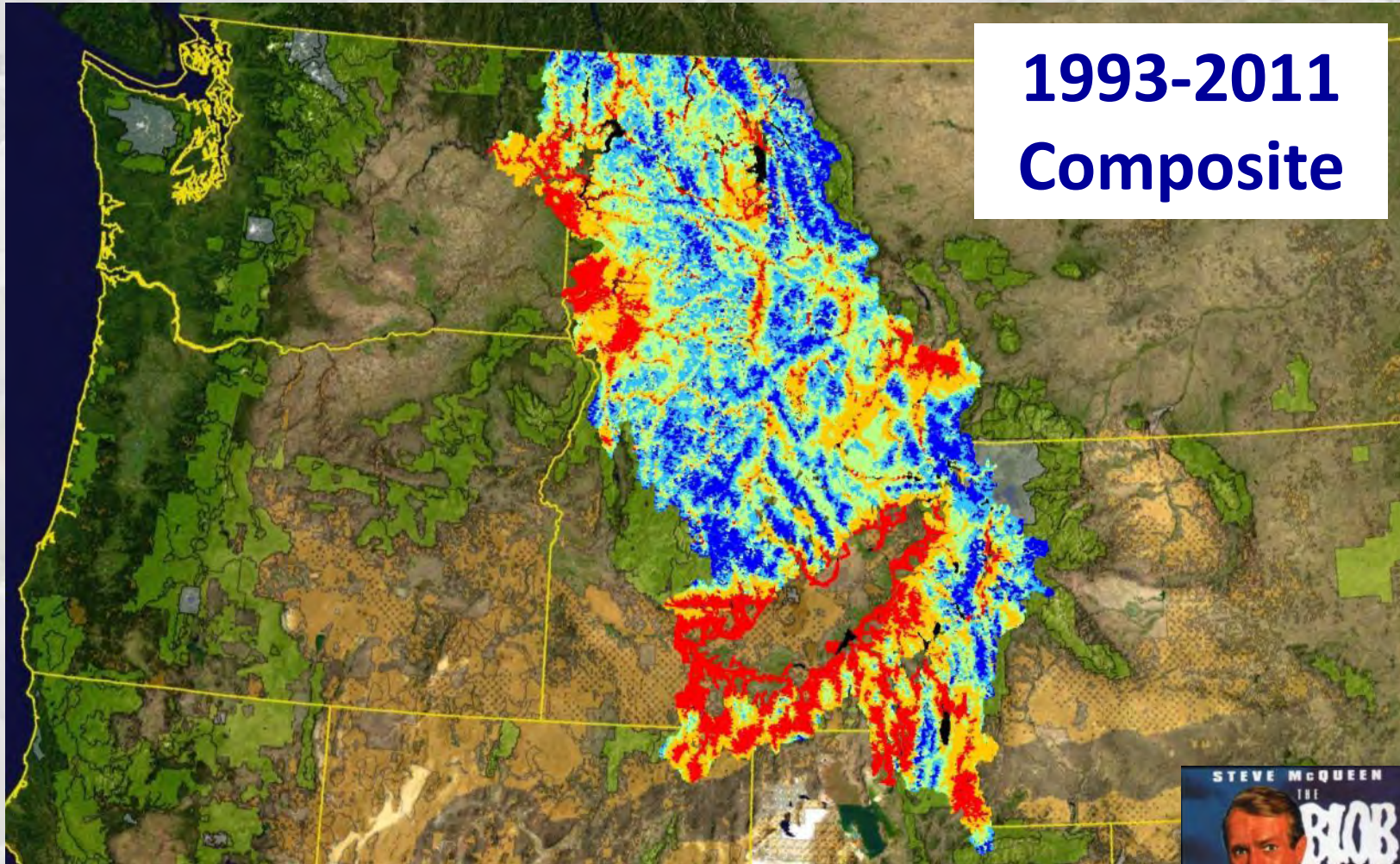
Temperature ( C )

- 3.0 - 8.0
- 8.1 - 10.0
- 10.1 - 12.0
- 12.1 - 15.0
- 15.1 - 27.0





# Climate Scenario Sequence



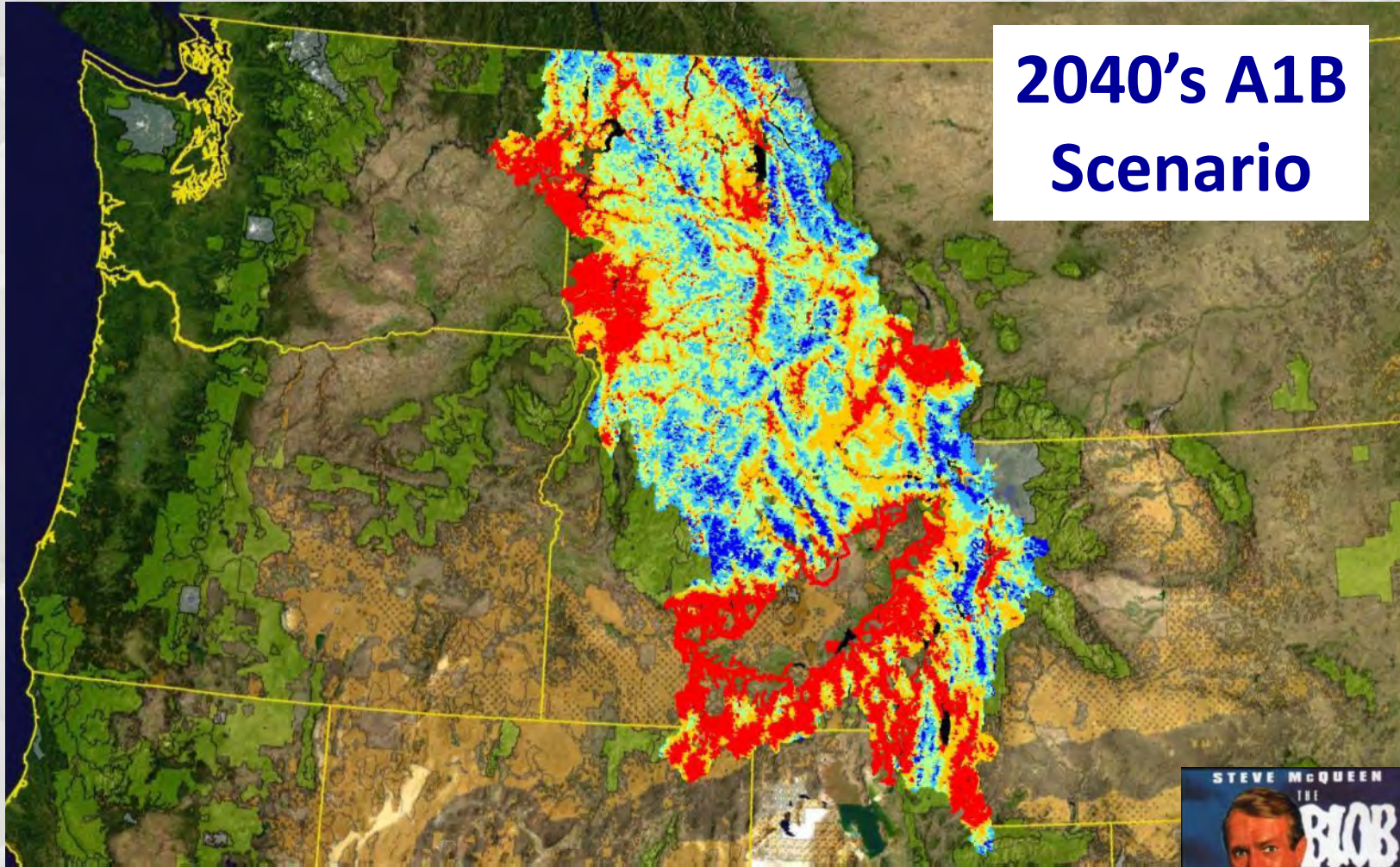
**The BLOB... it just keeps growing...**

- 171,000 stream kilometers of thermal ooze
- 16,688 summers of data swallowed





# Climate Scenario Sequence



**2040's A1B  
Scenario**

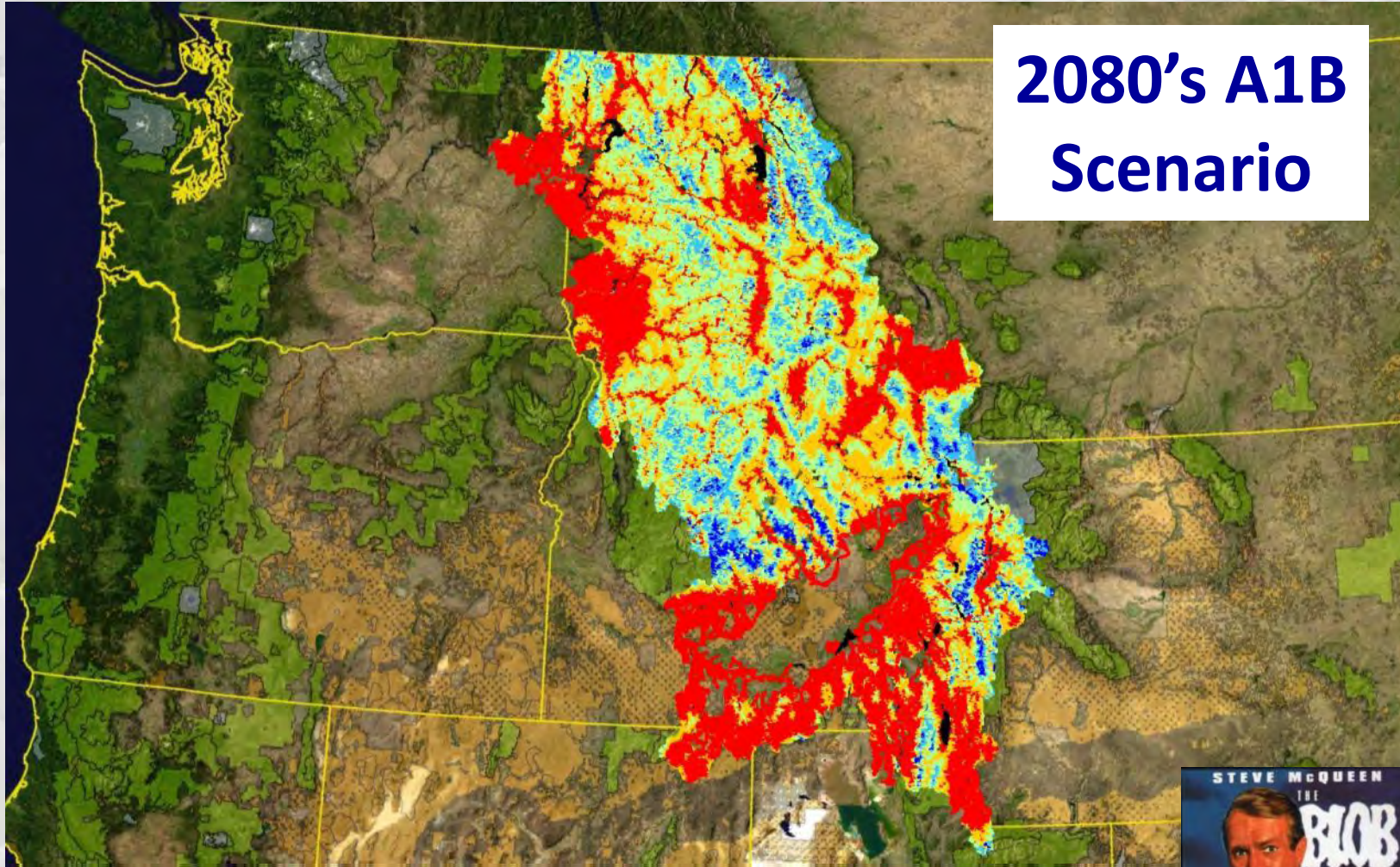
**The BLOB... it just keeps growing...**

- 171,000 stream kilometers of thermal ooze
- 16,688 summers of data swallowed





# Climate Scenario Sequence



**The BLOB... it just keeps growing...**

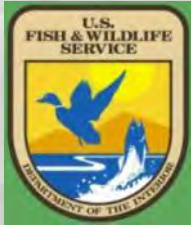
- 171,000 stream kilometers of thermal ooze
- 16,688 summers of data swallowed



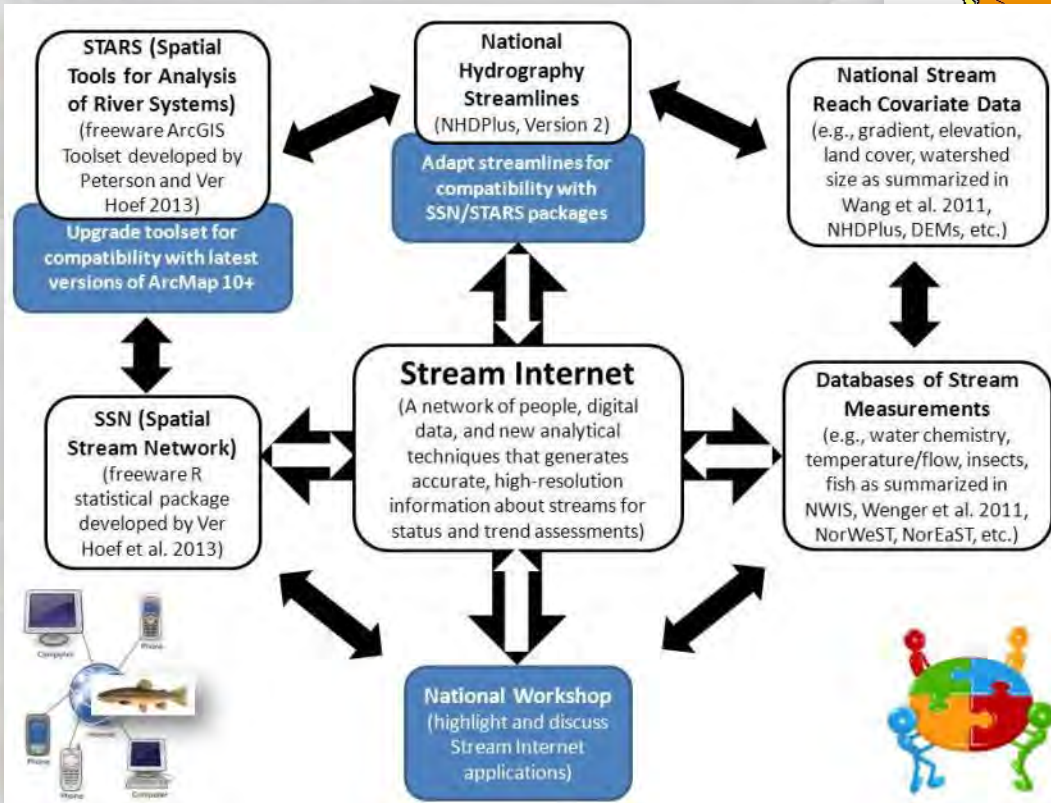
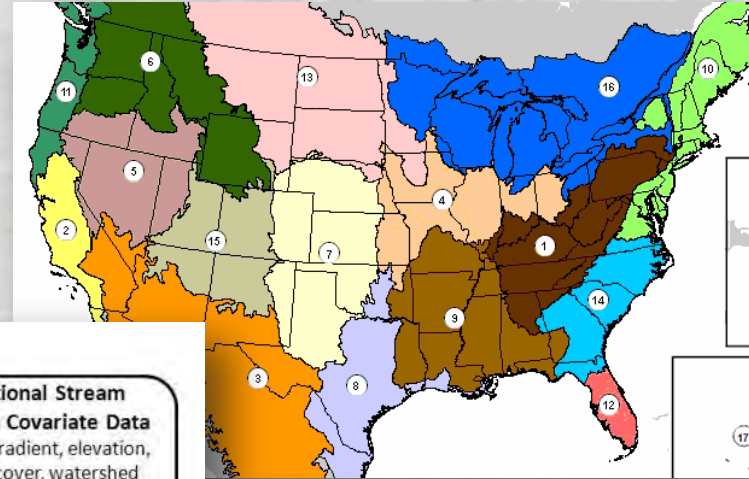


# BLOB Technologies Going National

## The Stream Internet Project



LANDSCAPE  
CONSERVATION  
COOPERATIVES



**Goal: develop analytical infrastructure that facilitates “Infinite Scaling” of stream data through space & time**



# Spatial Stream Models are Generalizable

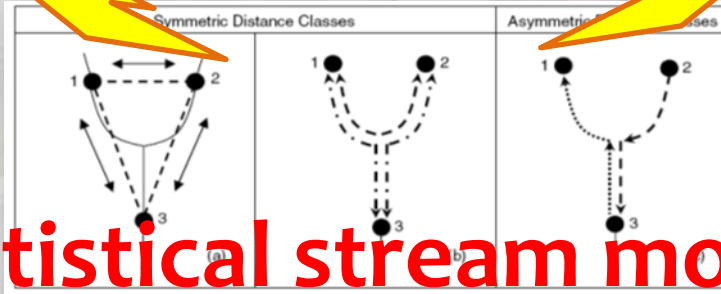
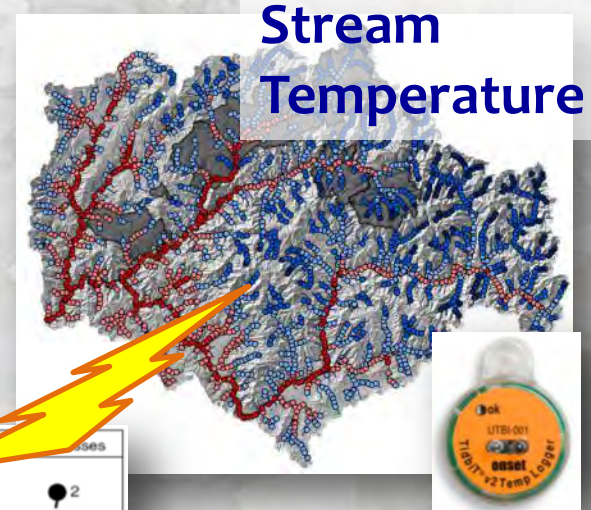


Distribution & abundance



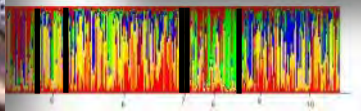
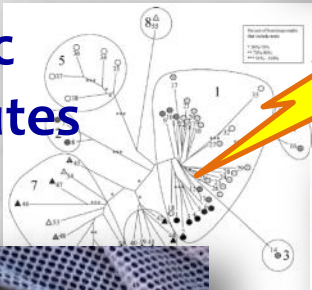
Response Metrics

- Gaussian
- Poisson
- Binomial



Statistical stream models

Genetic Attributes

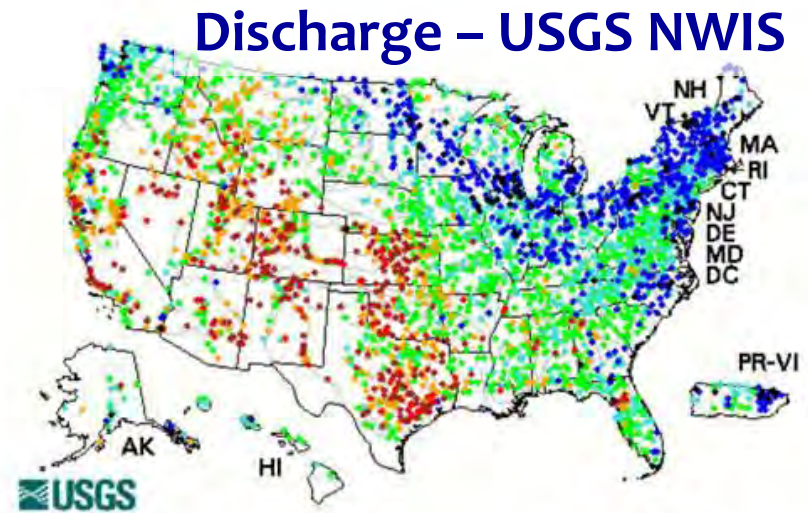
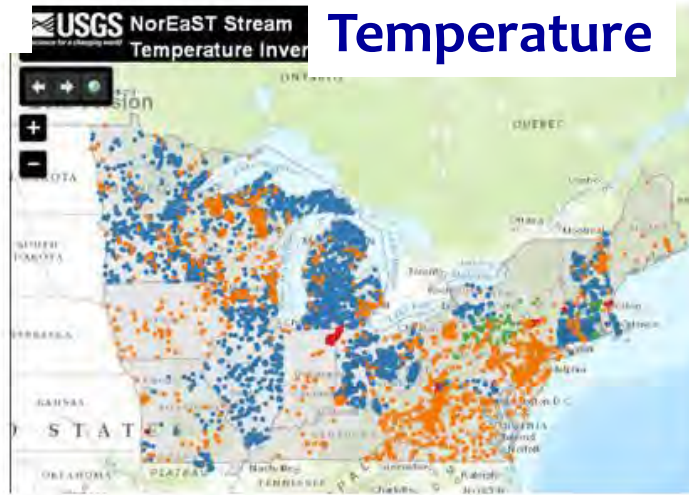


Water Quality Parameters

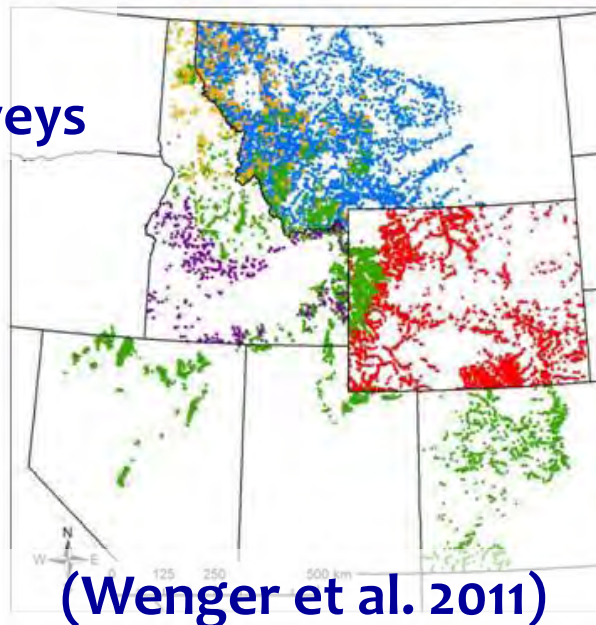




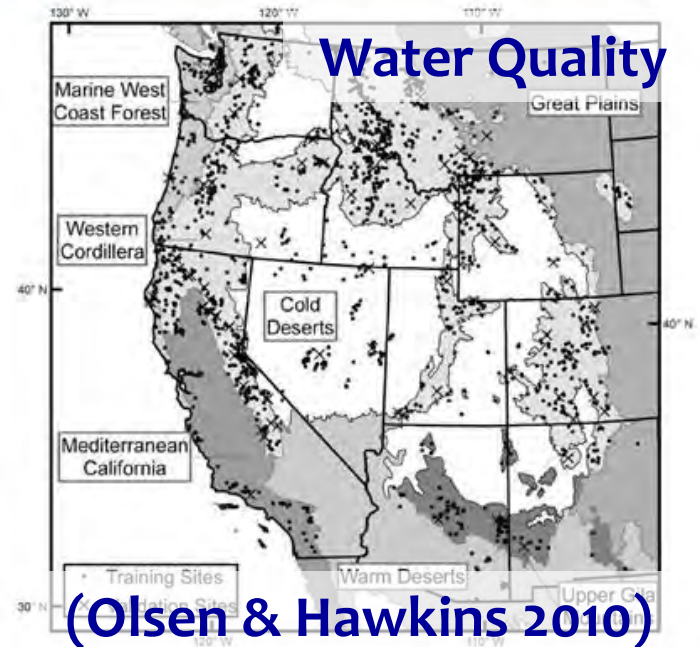
# & There's Lots of Data to Generalize About...



**Fish surveys**



**Water Quality**



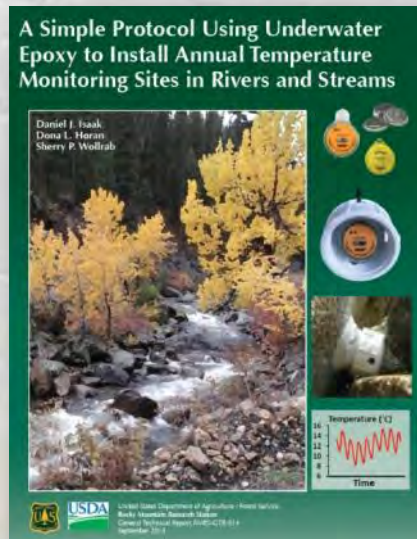


# Additional Resources...

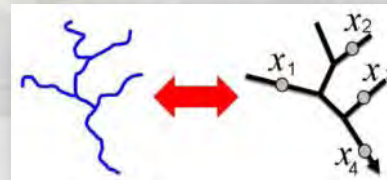
## Websites (Google Search On...)

- 1) **SSN/STARS** – statistical modeling of data on networks
- 2) **NorWeST** – regional stream temperature database & climate scenarios
- 3) **Stream Temperature Modeling & Monitoring**

## Publications...



## Software...



## Data...

