

NorWeST Stream Temperature Model: Data Structure, Covariates, & Applications

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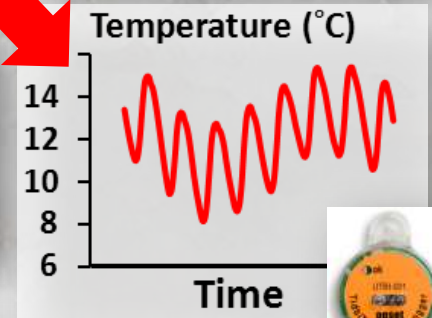
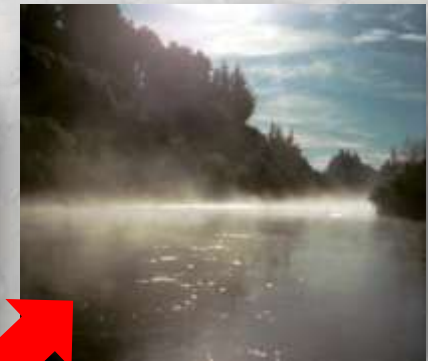
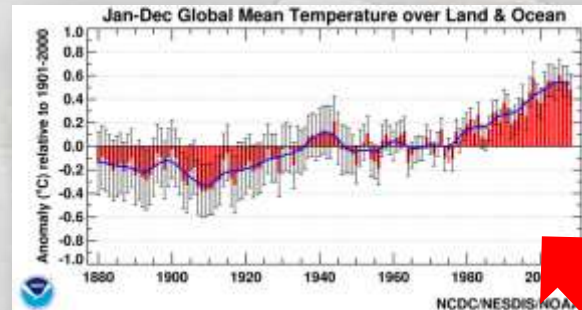
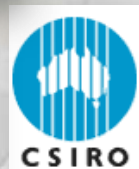
U.S. Forest Service

¹Trout Unlimited

²CSIRO

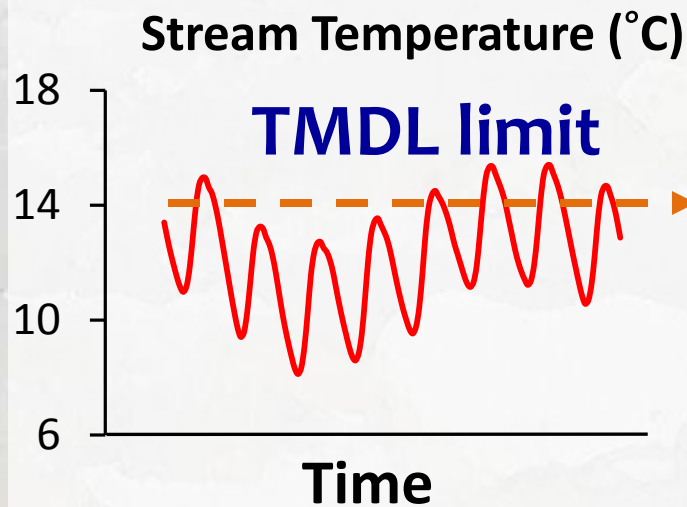
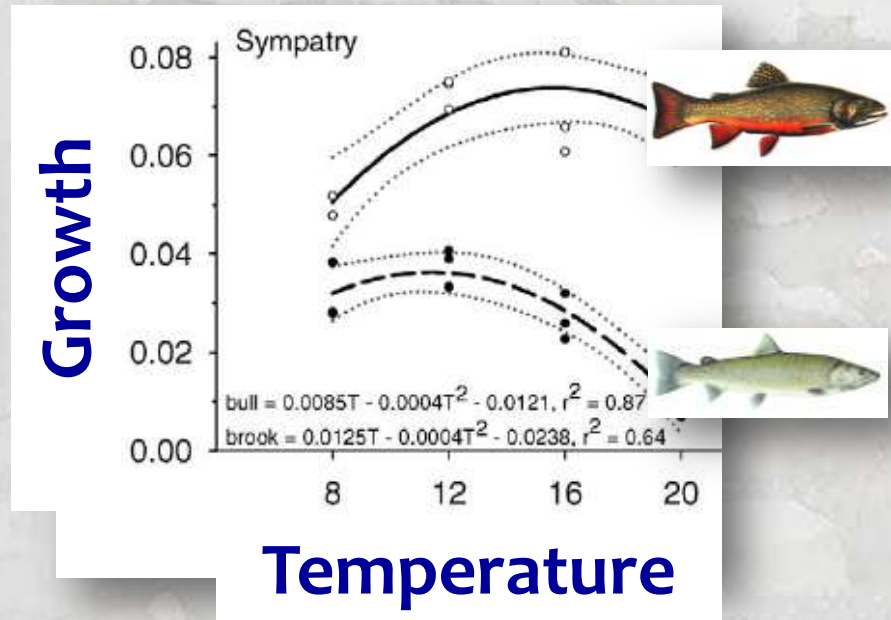
³NOAA

⁴USGS



Stream Temperature is “Climate” in Streams

Master variable for ectotherms

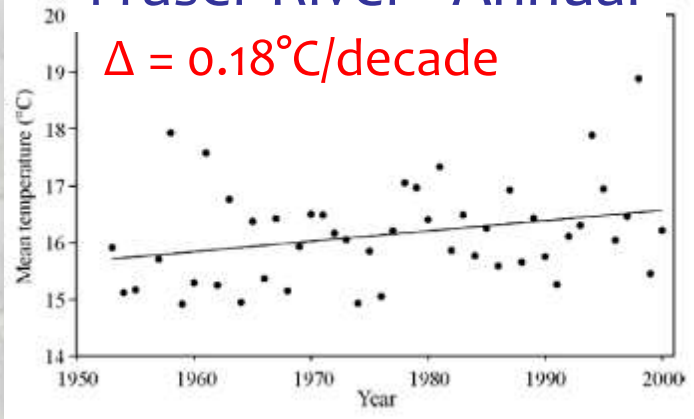


Too Hot!



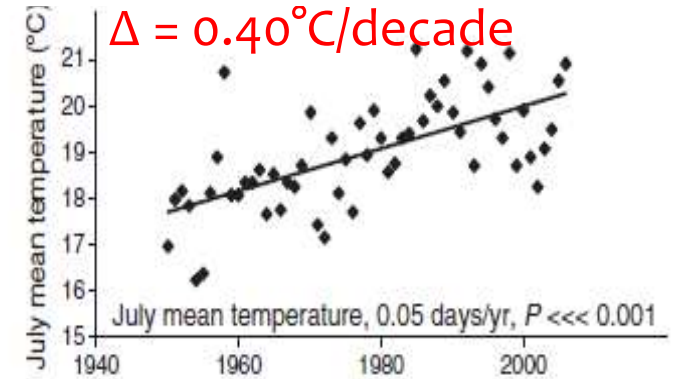
Temperature Trends In Northwest Rivers

Fraser River - Annual



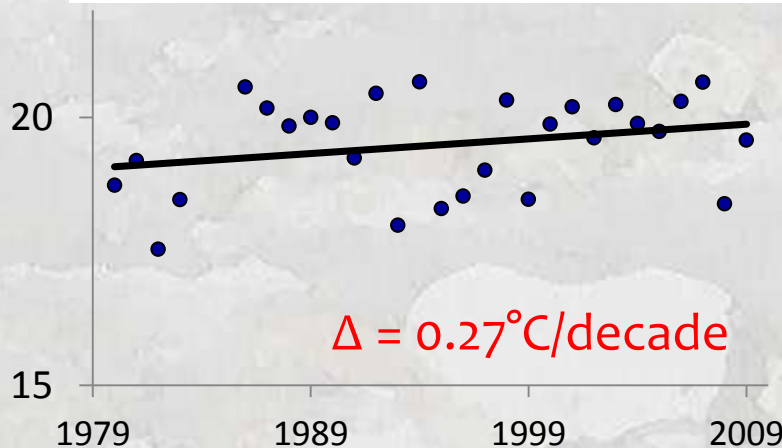
Morrison et al. 2001

Columbia River - Summer



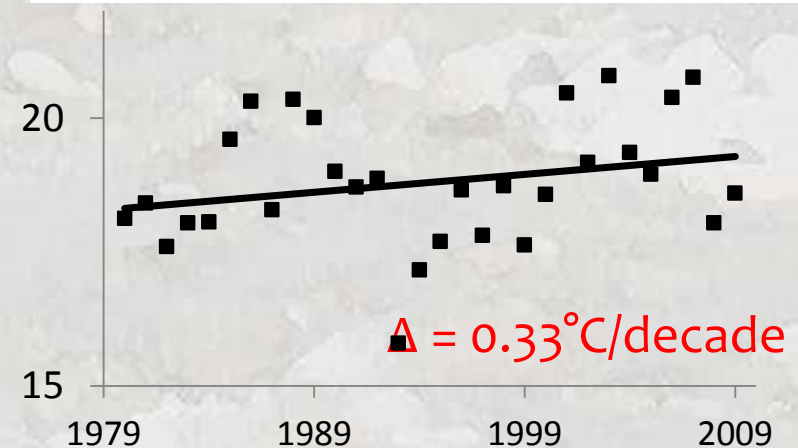
Crozier et al. 2008

Snake River, ID - Summer

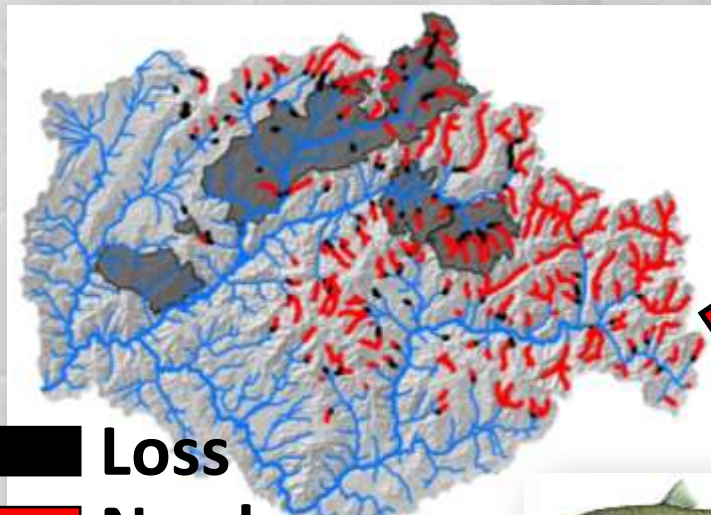
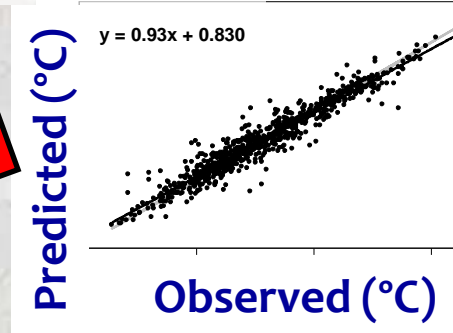
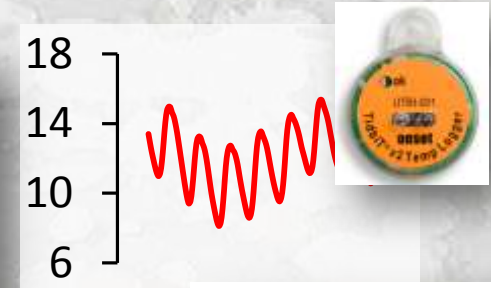
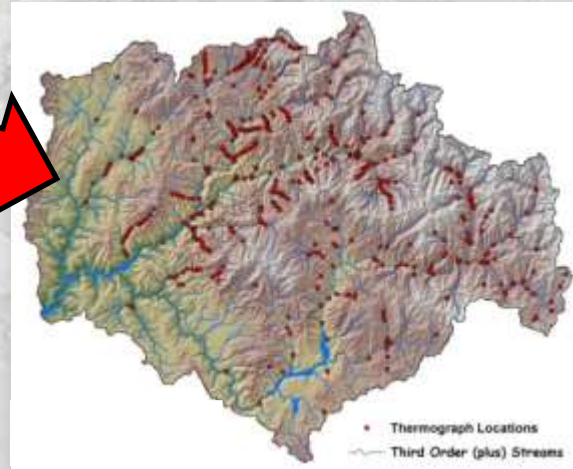


Isaak et al. 2012. *Climatic Change* 113:499-524.

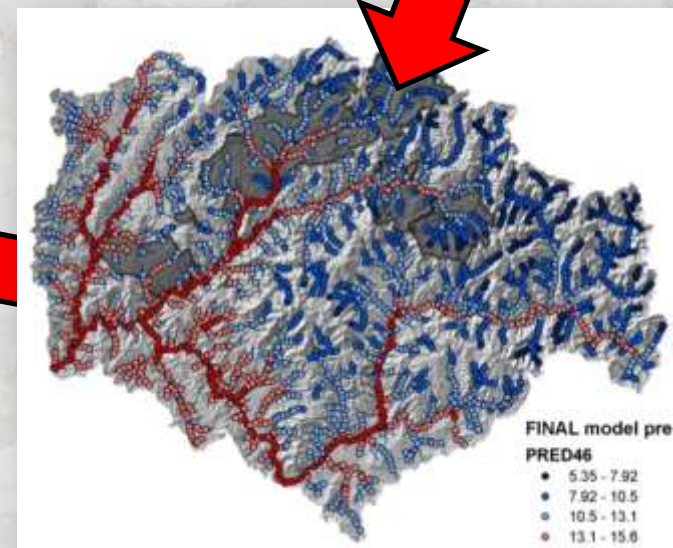
Missouri River, MT - Summer



Pilot Study: Boise River Basin



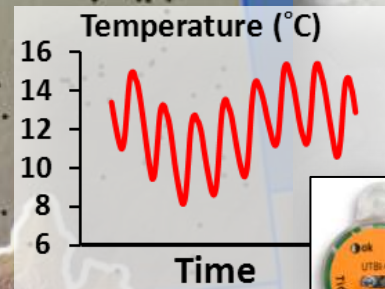
Loss
No change



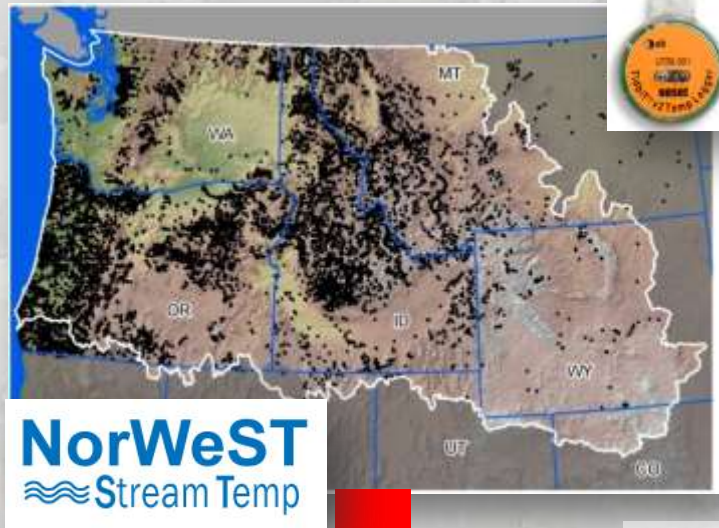
Larger Scale Replication...



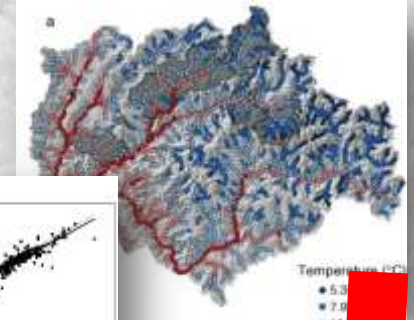
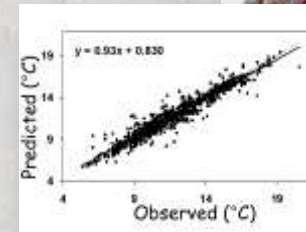
>50,000,000 hourly records
>15,000 unique stream sites
>80 resource agencies



Regional Temperature Model

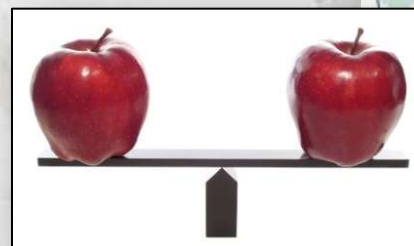
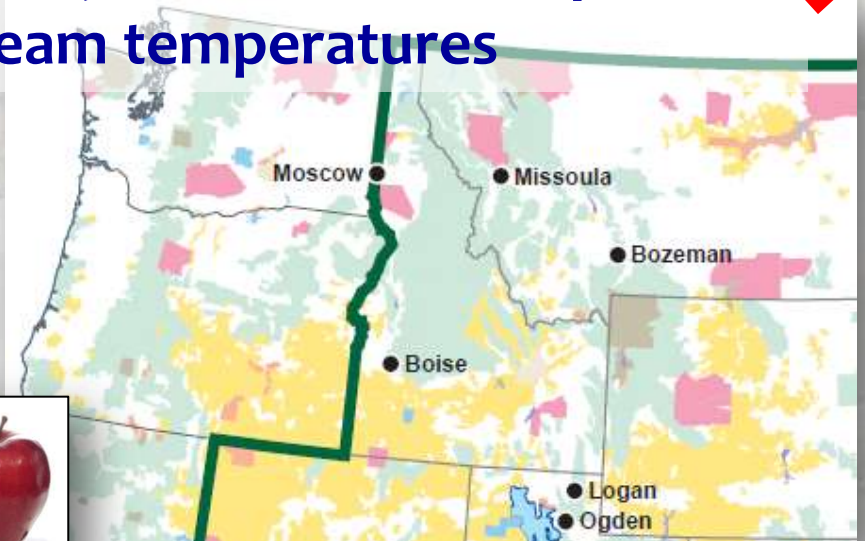


Accurate temperature models



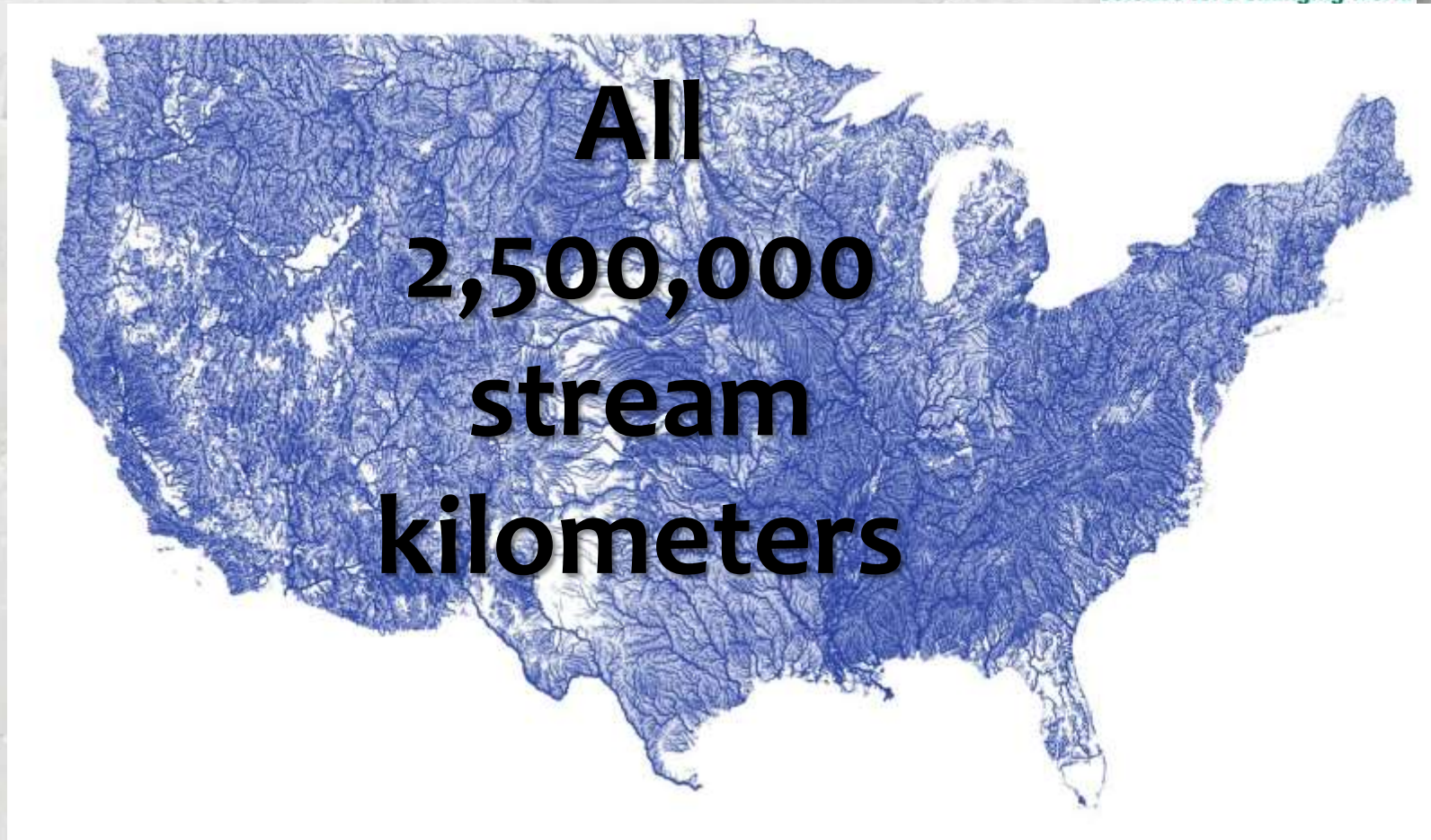
Cross-jurisdictional “maps” of stream temperatures

Consistent planning datum for 450,000 kilometers of stream



A Scale-able Approach

NHDPlus 1:100,000-Scale Streams

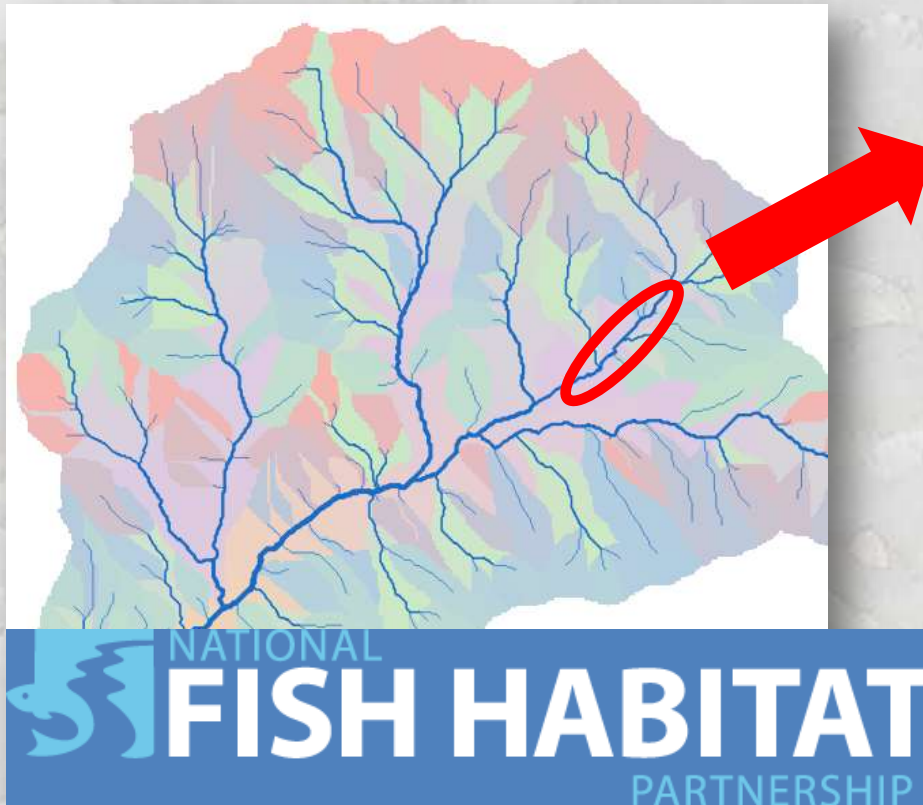


Cooter et al. 2010. A nationally consistent NHDPlus framework for identifying interstate waters: Implications for integrated assessments and interjurisdictional TMDLs.

Environmental Management 46:510-524.

A Scale-able Approach

NHDPlus 1:100,000-Scale Streams



Reach

Descriptors:

- Elevation
 - Slope
 - %Landuse
 - Precipitation
- 100's more...**

Wang et al. 2011. A Hierarchical Spatial Framework and Database for the National River Fish Habitat Condition Assessment. *Fisheries* **36**:436-449.

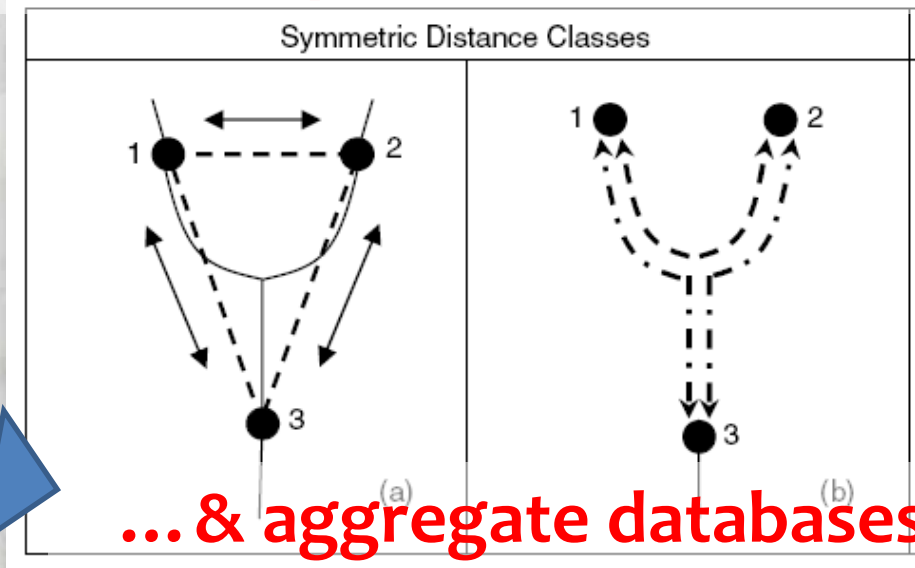
Cooter et al. 2010. A nationally consistent NHDPlus framework for identifying interstate waters: Implications for integrated assessments and interjurisdictional TMDLs. *Environmental Management* **46**:510-524.

“Found” 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

Spatial Stream Statistics Working Group



NCEAS

National Center for Ecological Analysis and Synthesis

Software refinements & applications

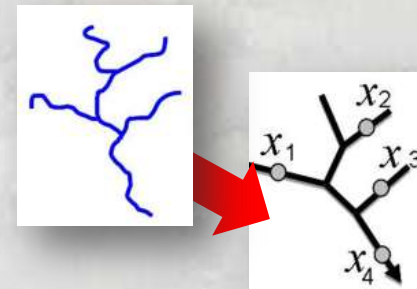
Isaak, D.J., E. Peterson, J. V. Hoef, S. Wenger, J. Falke, C. Torgersen, C. Sowder, A. Steel, M.J. Fortin, C. Jordan, A. Reusch, N. Som, P. Monestiez. 2014. Applications of spatial statistical network models to stream data. **WIREs - Water** 1:27-294.

Peterson E.E. & Ver Hoef J.M. 2014. STARS: An ArcGIS toolset used to calculate the spatial information needed to fit spatial statistical models to stream network data. **Journal of Statistical Software** 56(2):1-17.

Peterson E.E., Ver Hoef J.M., Isaak D.J., Falke J.A., Fortin M.J., Jordan C., McNyset K., Monestiez P., Ruesch A.S., Sengupta A., Som N., Steel A., Theobald D.M., Torgersen C.T. & Wenger S.J. 2013. Modeling dendritic ecological networks in space: an integrated network perspective. **Ecology Letters** 16:707-719.

Som N.A., Monestiez P., Zimmerman D.L., Ver Hoef J.M. & Peterson E.E. In Press. Spatial sampling on streams: Principles for inference on aquatic networks. **Environmetrics** x:xxx.

Ver Hoef J.M., Peterson E.E., Clifford D. & Shah R. 2014. SSN: An R package for spatial statistical modeling on stream networks. **Journal of Statistical Software** 56(3):1-45.



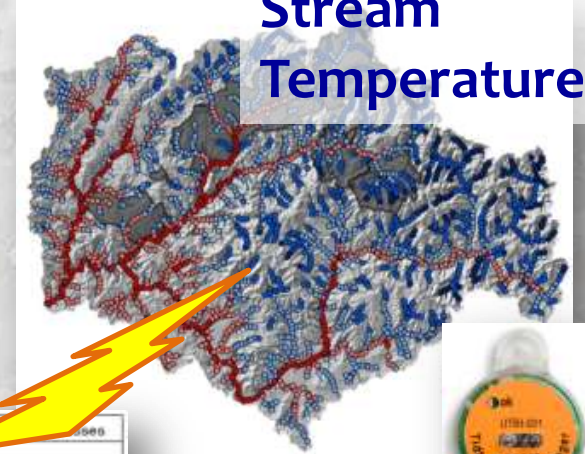
Stream Models are Generalizable...



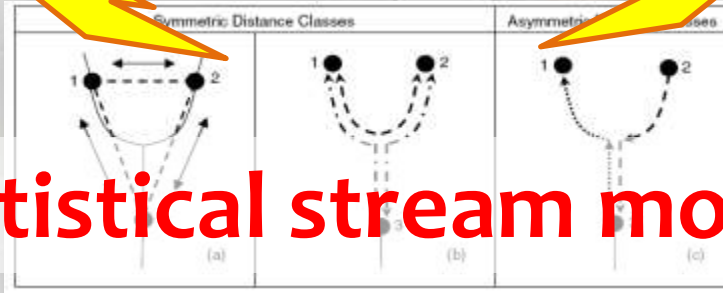
Distribution & abundance

Response Metrics

- Gaussian
- Poisson
- Binomial

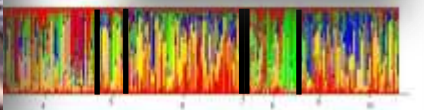
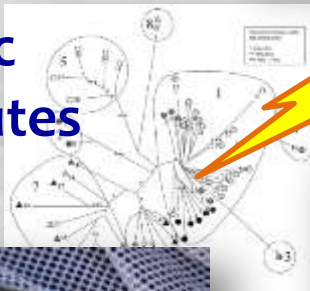


Stream Temperature



Statistical stream models

Genetic Attributes

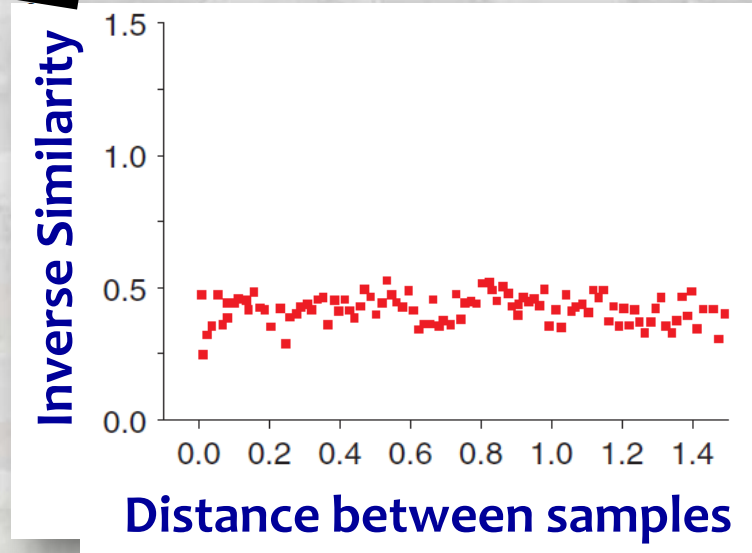
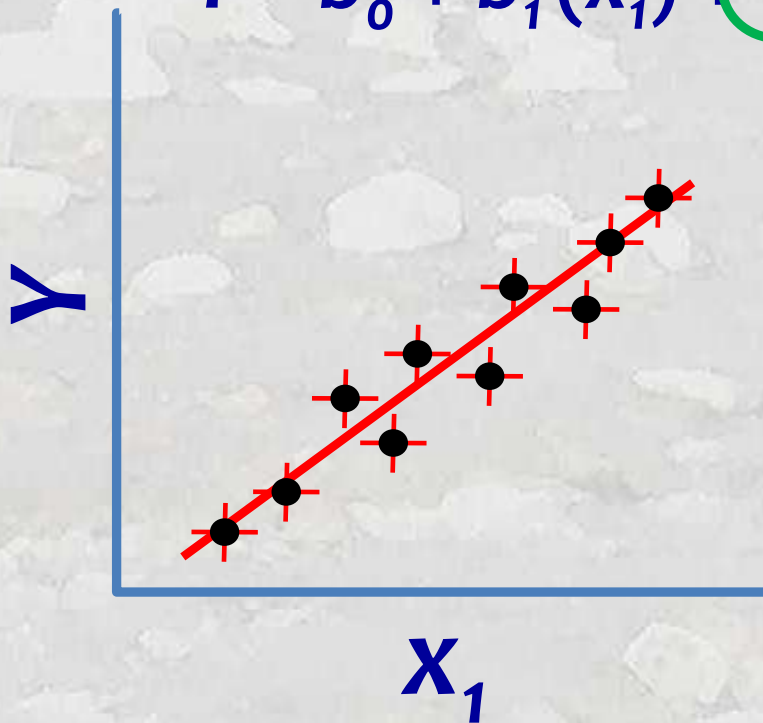


Water Quality Parameters



Linear Statistical Model

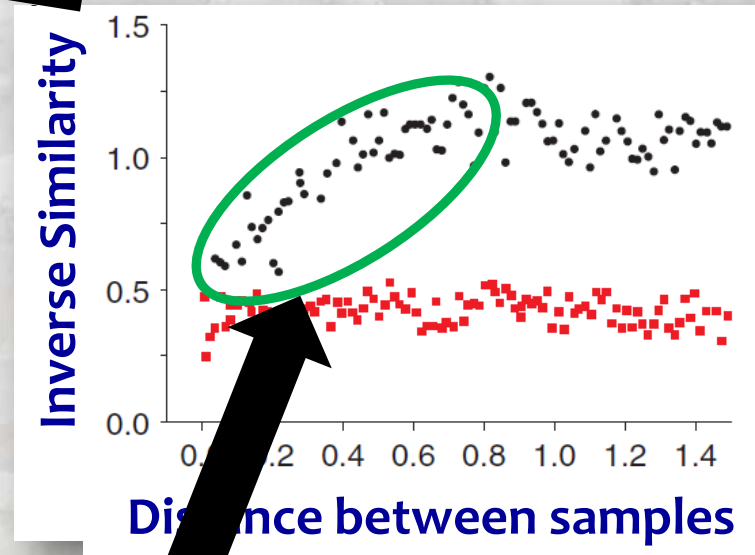
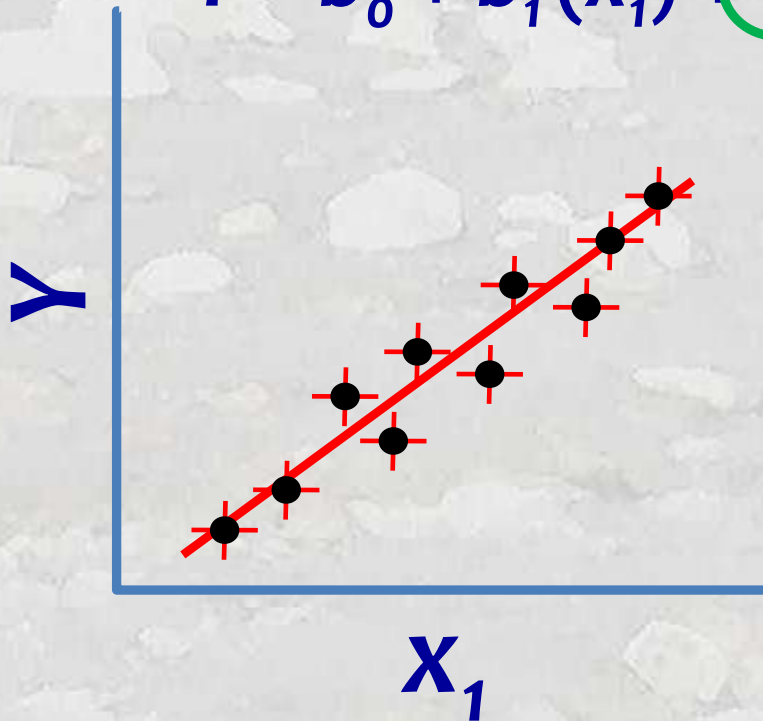
$$Y = b_0 + b_1(x_1) + \epsilon$$



Isaak et al. 2014. Applications of spatial statistical network models to stream data. *WIREs - Water* 1:27-294.

Linear Statistical Model

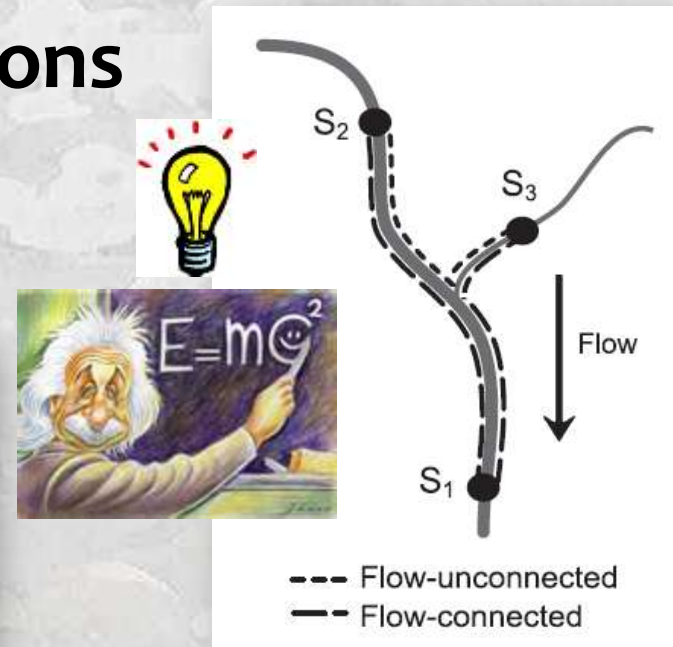
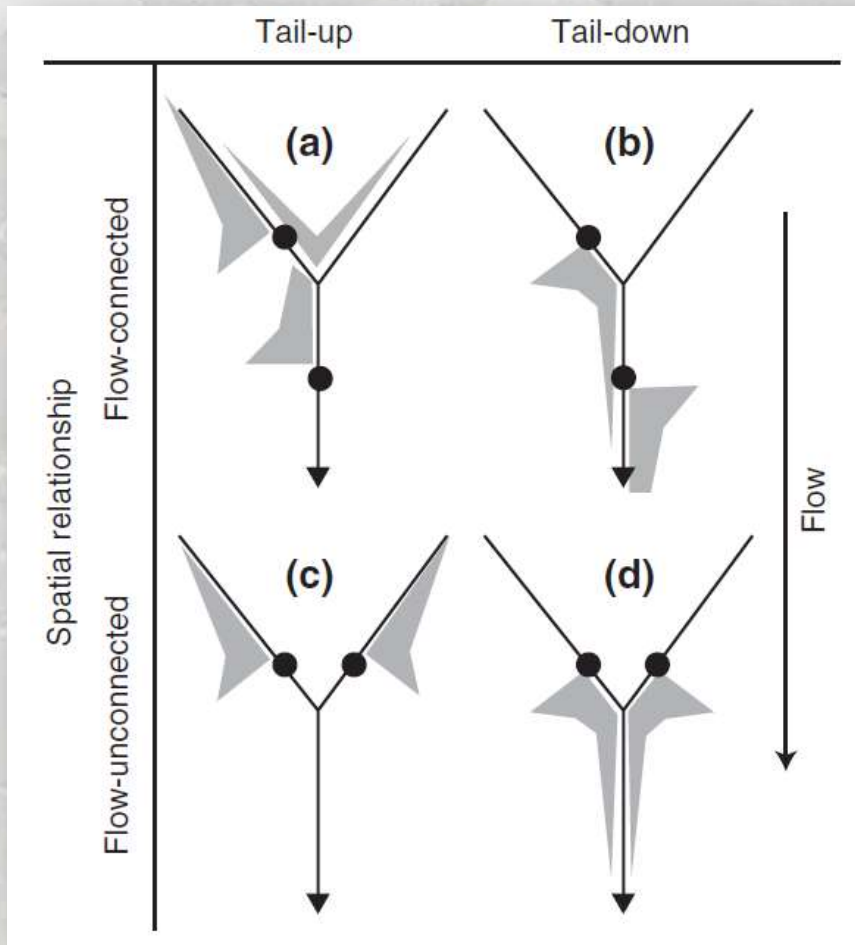
$$Y = b_0 + b_1(x_1) + \epsilon$$



AutoCovariance Function Models Spatial Structure in Residual Errors

Isaak et al. 2014. Applications of spatial statistical network models to stream data. *WIREs - Water* 1:27-294.

Autocovariance functions based on network structure



- Models deal with spatial autocorrelation among observations (non-independence)

Peterson et al. 2007. *Freshwater Biology* 52:267-279;

Peterson & Ver Hoef. 2010. *Ecology* 91:644-651.

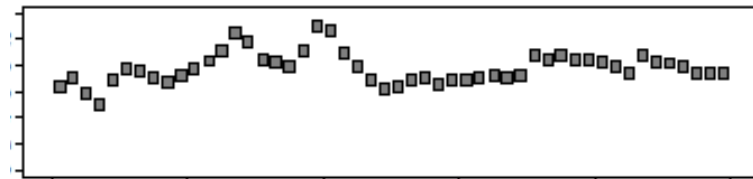
Autocovariance Structure is “Black Box”

Spatial patterns in residual errors of MWMT model

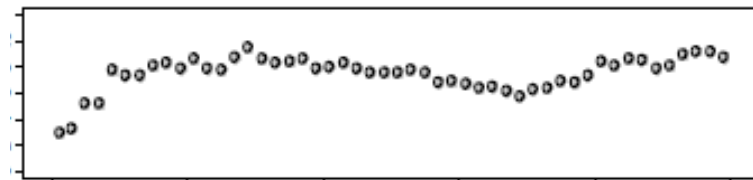
Semivariance



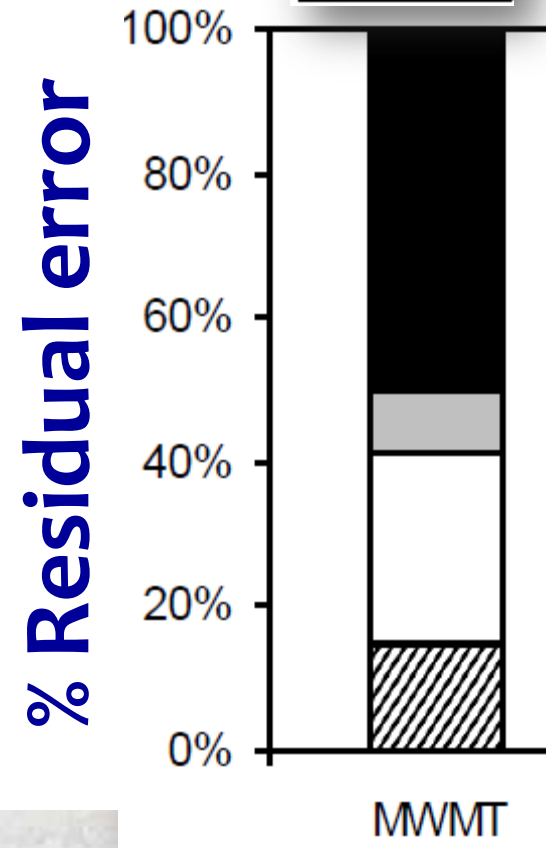
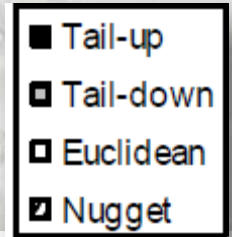
Tail-down distance (km)



Tail-up distance (km)

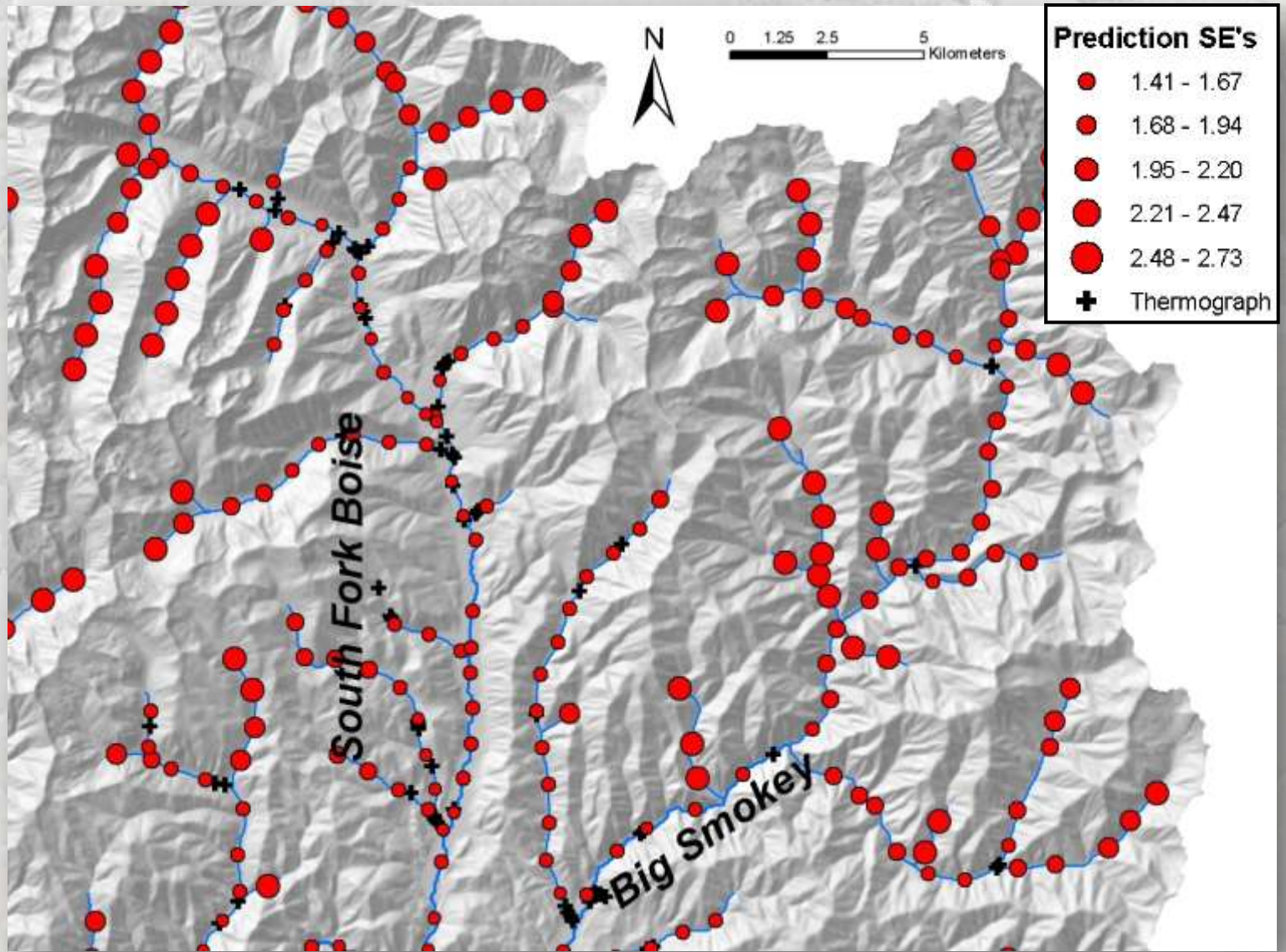


Euclidean distance (km)

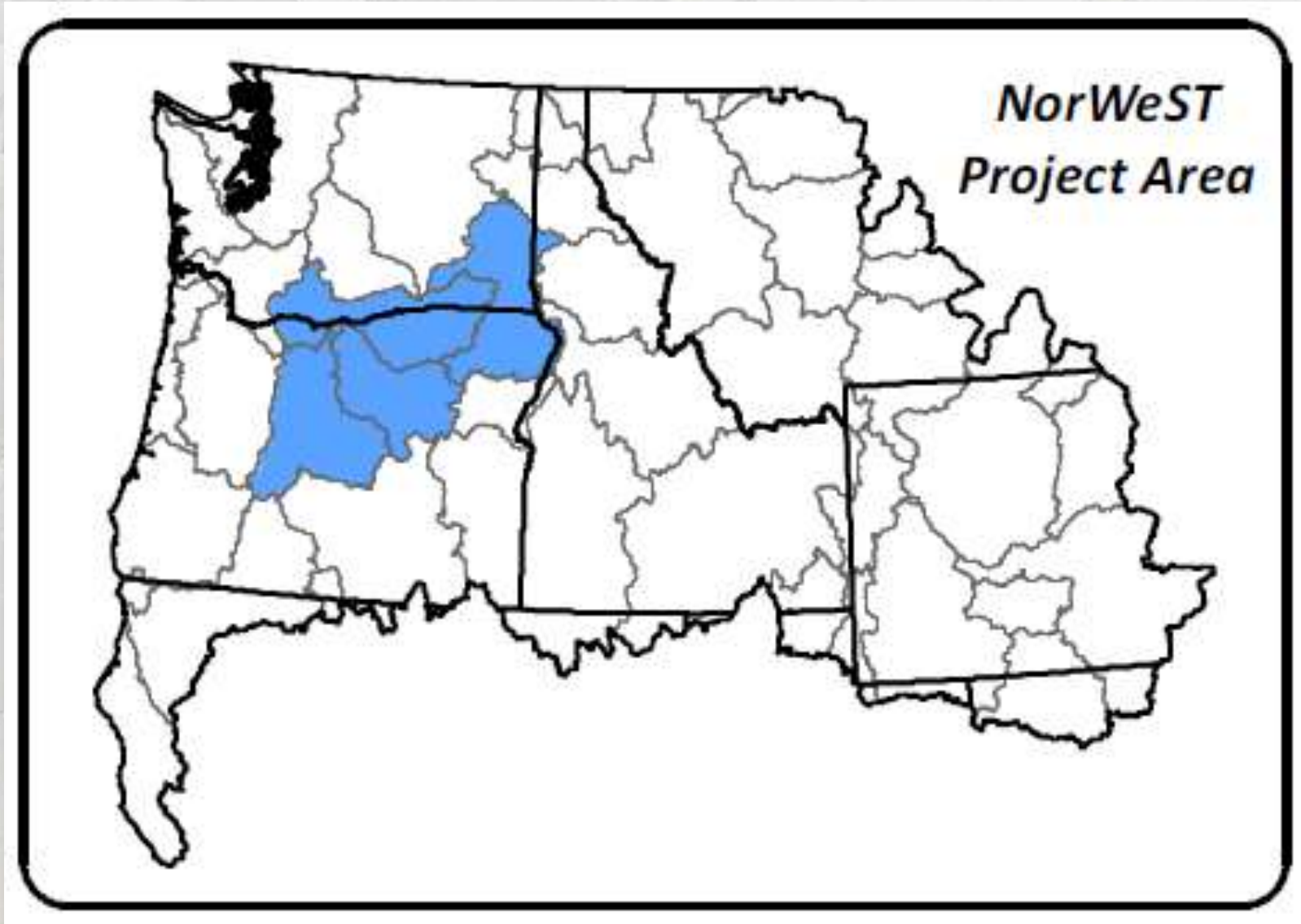


Model Prediction Maps “Kriging”

Measurement sites provide local calibration



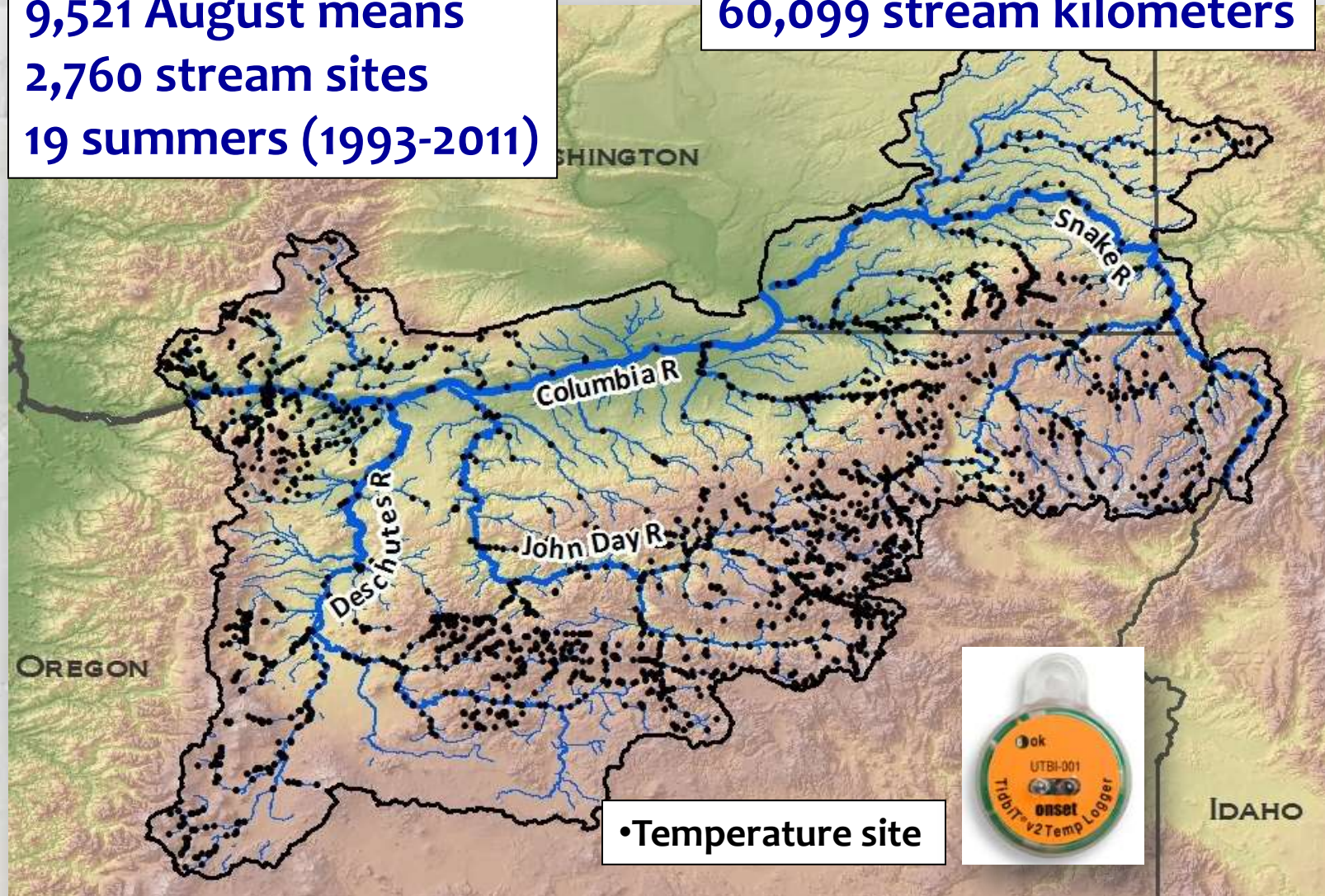
Temperature Dataset for Mid-Columbia



Temperature Dataset for Mid-Columbia

9,521 August means
2,760 stream sites
19 summers (1993-2011)

60,099 stream kilometers



Mid-Columbia Temperature Model

n = 9,521

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 (km²)
9. Glacier (%)

10. Discharge (m³/s)

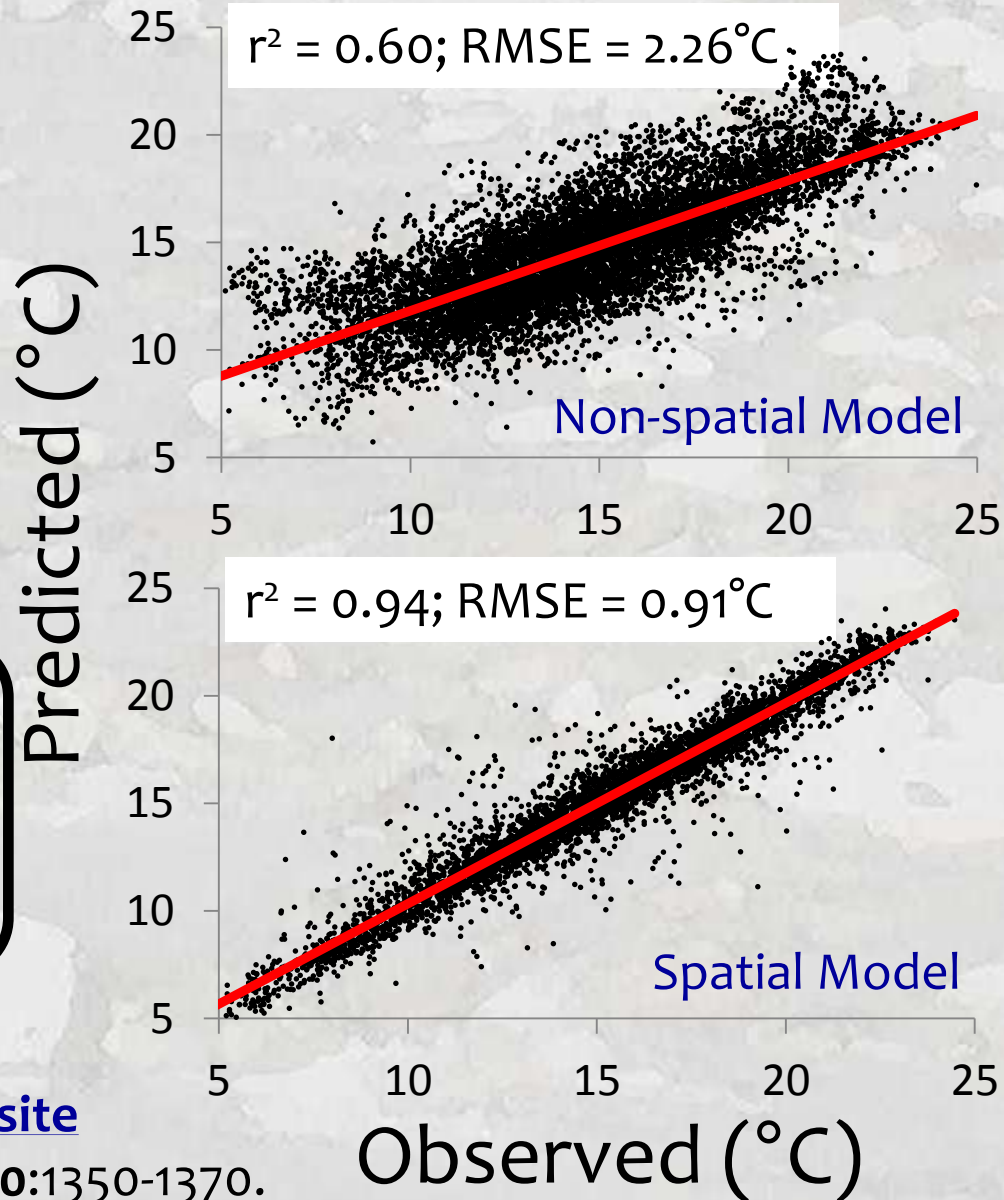
USGS gage data

11. Air Temperature (°C)

RegCM3 NCEP reanalysis

Hostetler et al. 2011

Mean August Temperature



More details: [NorWeST website](#)

Isaak et al. 2010. *Ecol. Apps* 20:1350-1370.

NorWeST Predictor Variable Sources

Predictor	Data Source
1. Stream slope	NHD+
2. %Glacier (ICE&SNOW)	NHD+ (NLCD)
3. %Lake (OPEN WATER)	NHD+ (NLCD)
4. Annual precipitation (AREAWTMAP)	NHD+
5. Stream width (CUMDRAINAG)	NHD+
6. Riparian Canopy %	NLCD 2001
7. Elevation	30 m DEM
8. Baseflow Index (BFI)	Santhi et al. 2008
9. Latitude	UTM coordinate
10. August Discharge Mean*	USGS gages
11. August Air Mean*	NCEP RegCM3 reanalysis

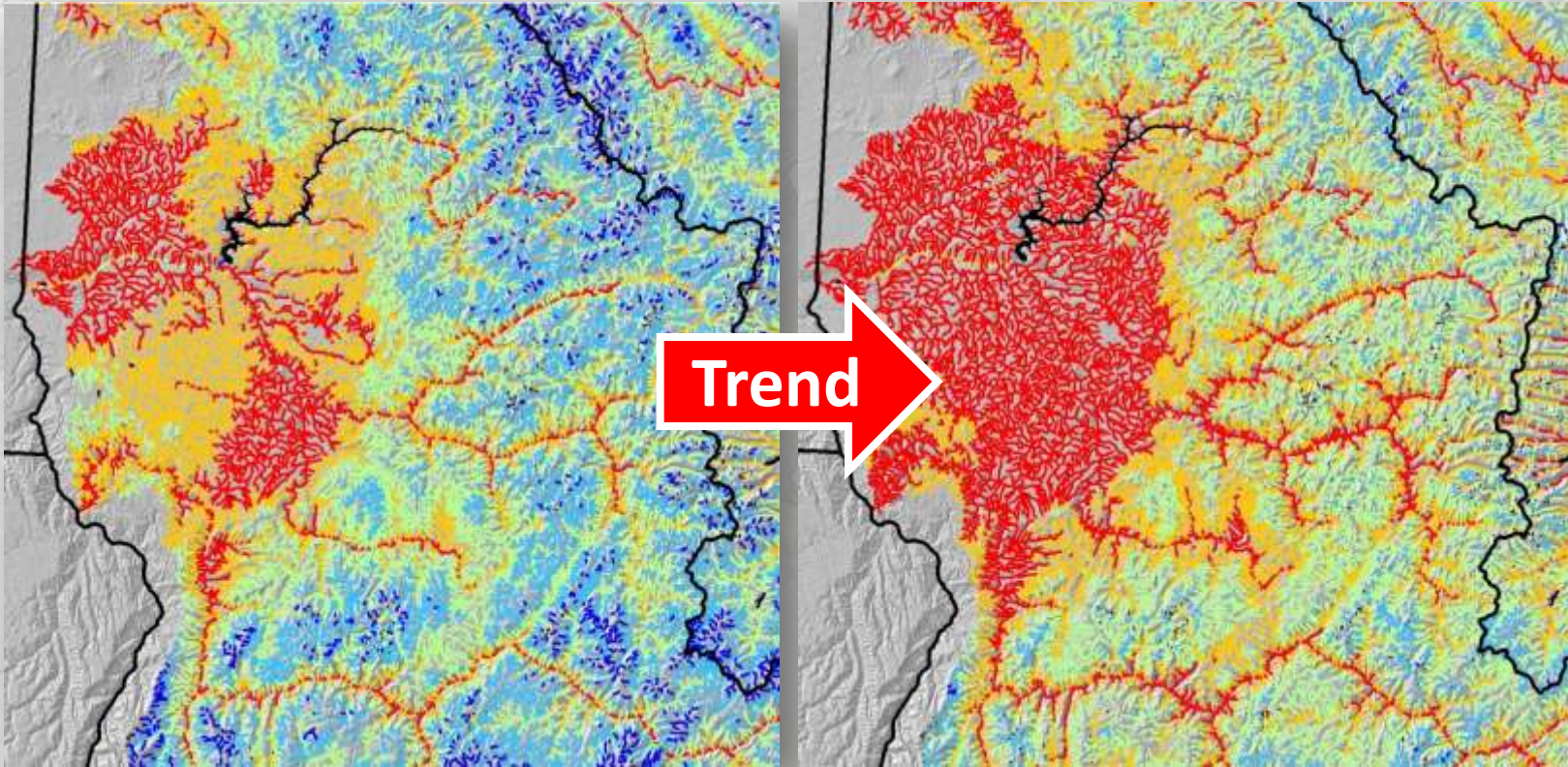
*Inter-annual climate variation

Kriged Network Prediction Maps

Network-scale *Status* Maps

Time 1

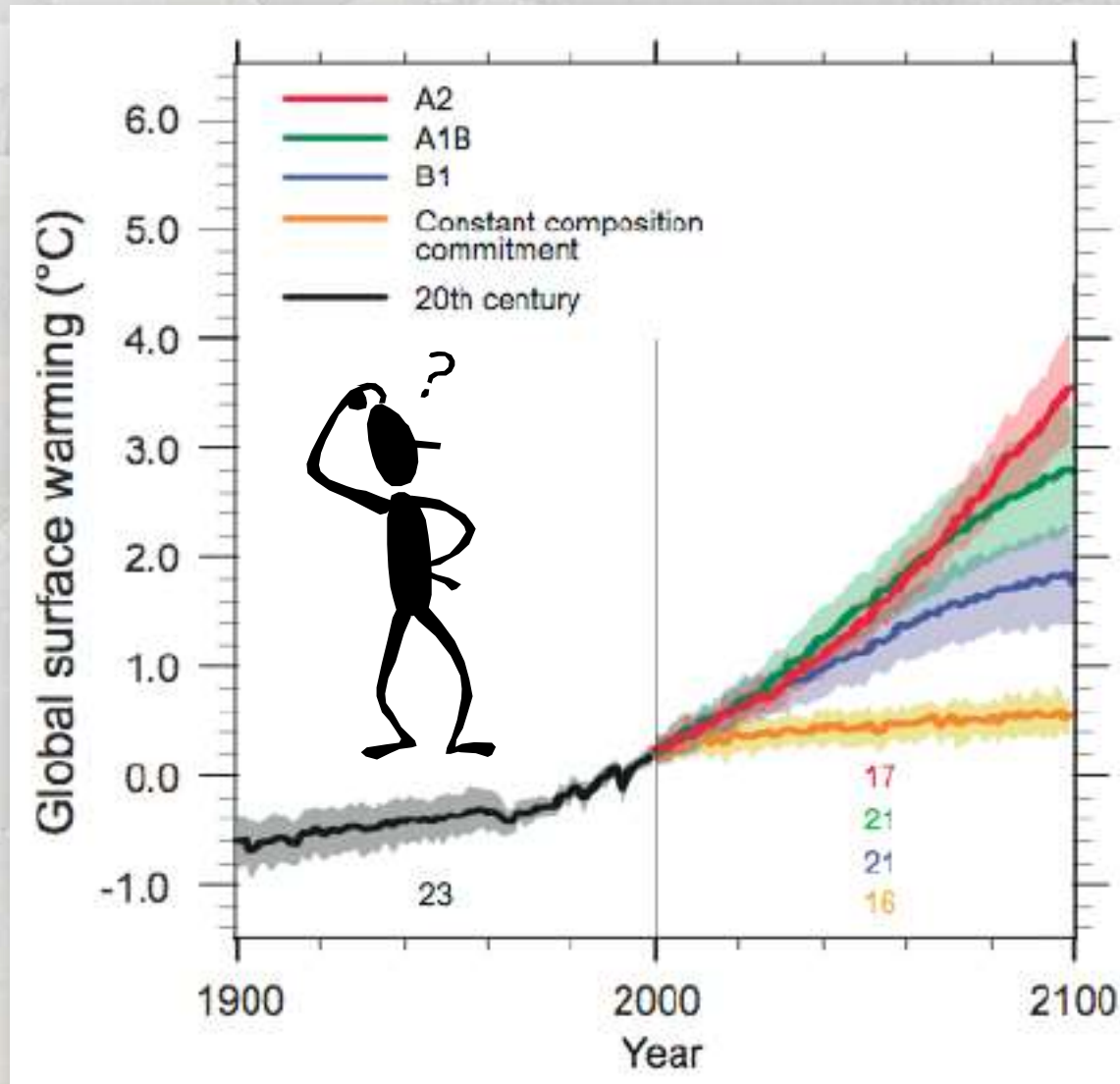
Time 2



Which then facilitate trend assessments...

Models Enable Climate Scenario Maps

Many possibilities exist...



Adjust...

- Air
- Discharge
- %Canopy

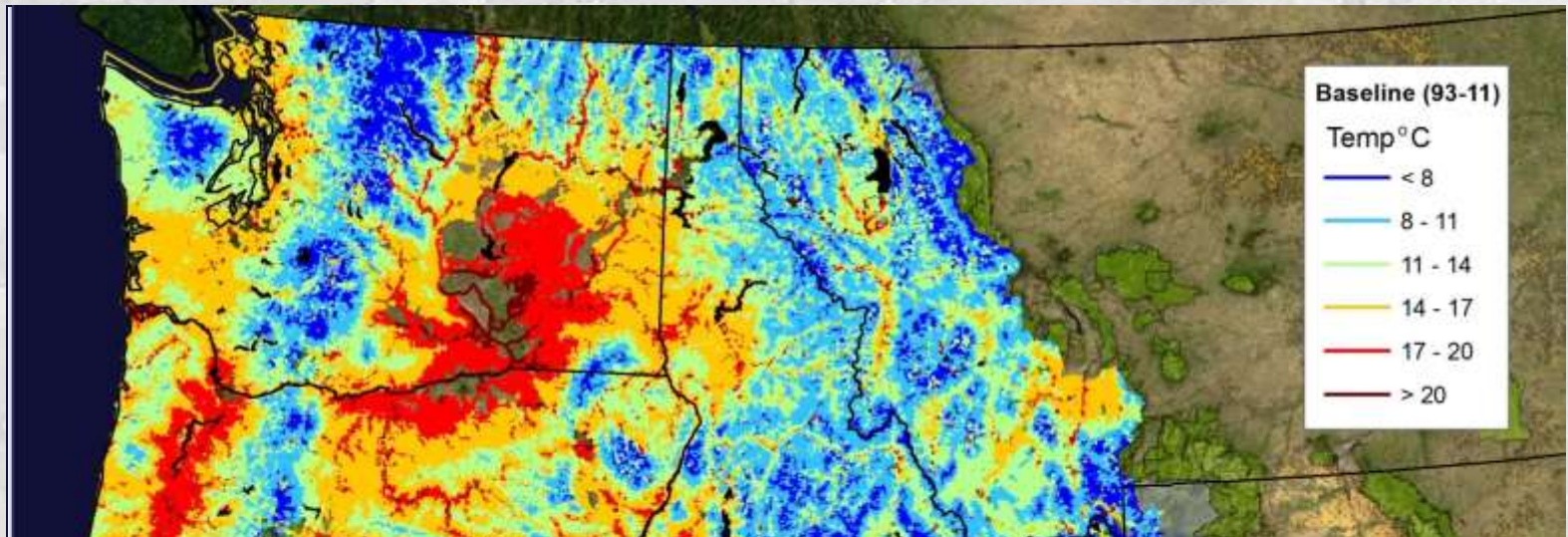
... values to
create scenarios

NorWeST Historical Scenarios

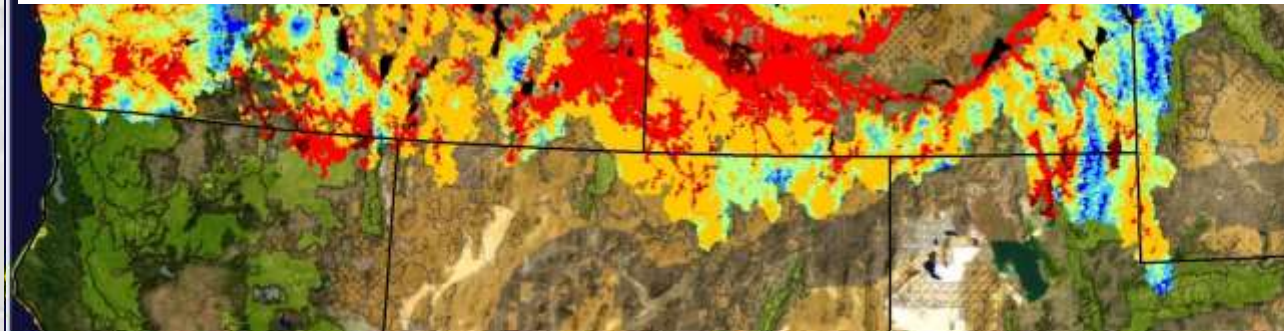
Scenario	Description
S1_93_11	Historical scenario representing 19 year average August mean stream temperatures for 1993-2011
S2_02_11	Historical scenario representing 10 year average August mean stream temperatures for 2002-2011
S3_1993	Historical scenario representing August mean stream temperatures for 1993
S4_1994	Historical scenario representing August mean stream temperatures for 1994
Etc...	
S21_2013	Historical scenario representing August mean stream temperatures for 2013

***Extensive metadata on website**

High-Resolution Stream Temp Scenarios



$R^2 = 0.91$; RMSE = 1.0°C ; 1-km resolution

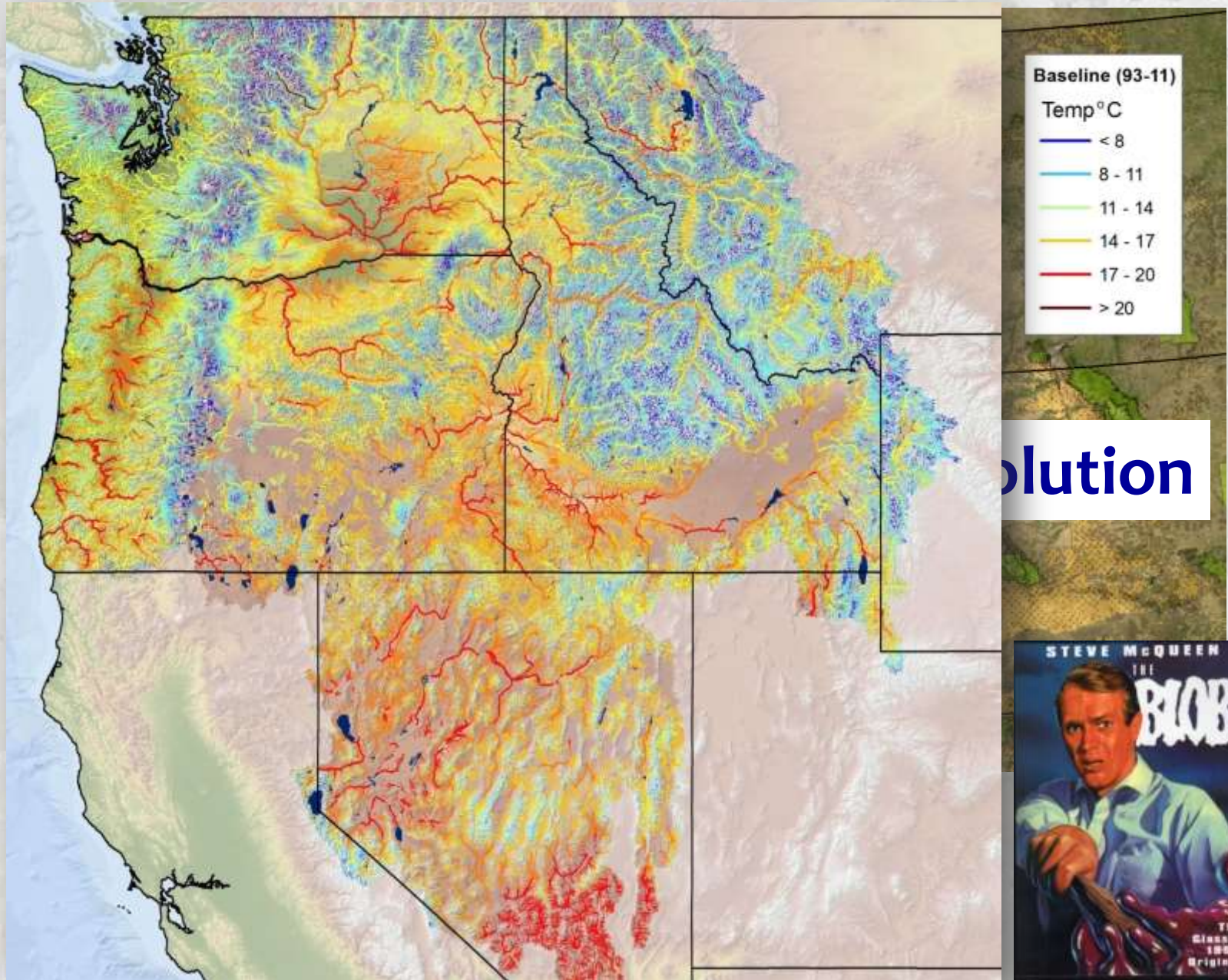


The BLOB... it just keeps growing...

- 46,674 summers of data swallowed
- 467,000 stream kilometers of thermal ooze

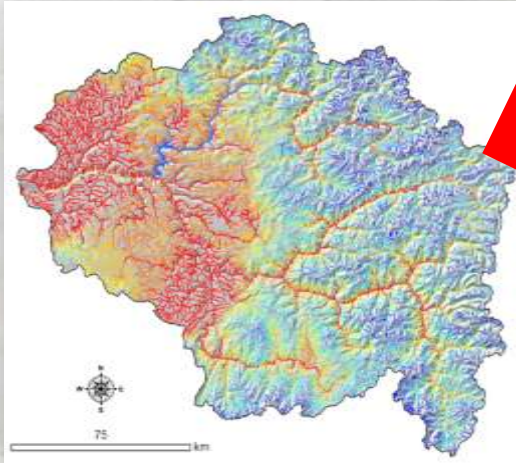


High-Resolution Stream Temp Scenarios



Website Distributes Temperature Data & Scenarios for Convenient Use

1) GIS shapefiles of stream temperature scenarios

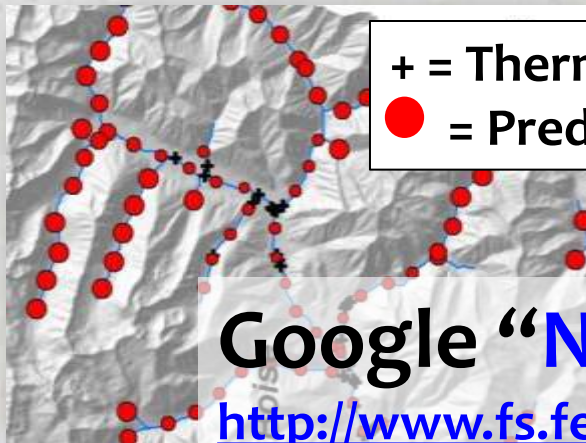


NorWeST
Stream Temp



Regional Database and Modeled Stream Temperatures

2) GIS shapefiles of stream temperature model prediction precision



+ = Thermograph
● = Prediction SE

3) Temperature data summaries

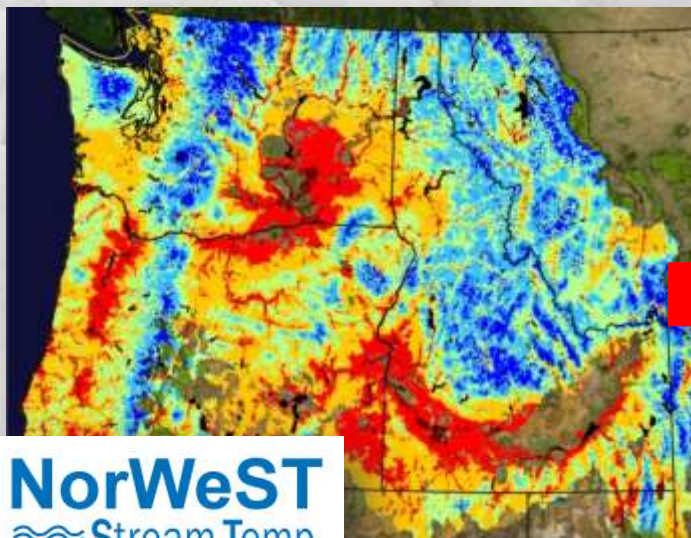


Google “**NorWeST**” or go here...

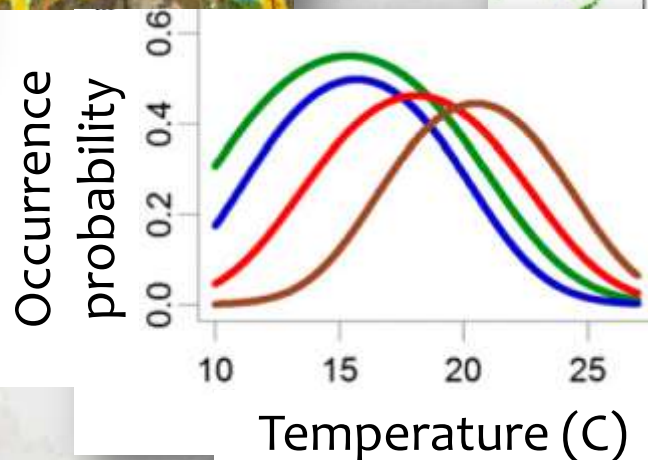
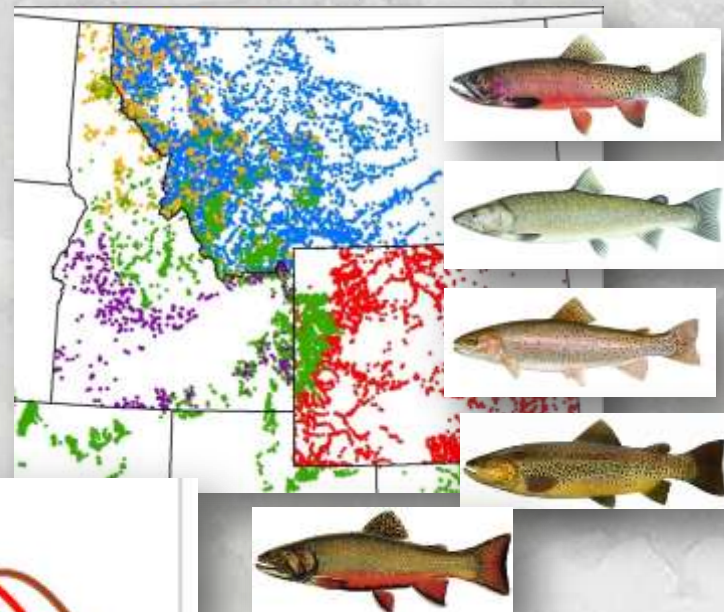
<http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.shtml>

Field-Based Temperature Standards using BIG FISH Databases

Stream temperature maps



Regional fish survey databases (n ~ 13,000)



Wenger et al. 2011a. *PNAS* **108**:14175-14180

Wenger et al. 2011b. *CJFAS* **68**:988-1008; Wenger et al., *In Preparation*

A Generalizable Approach...

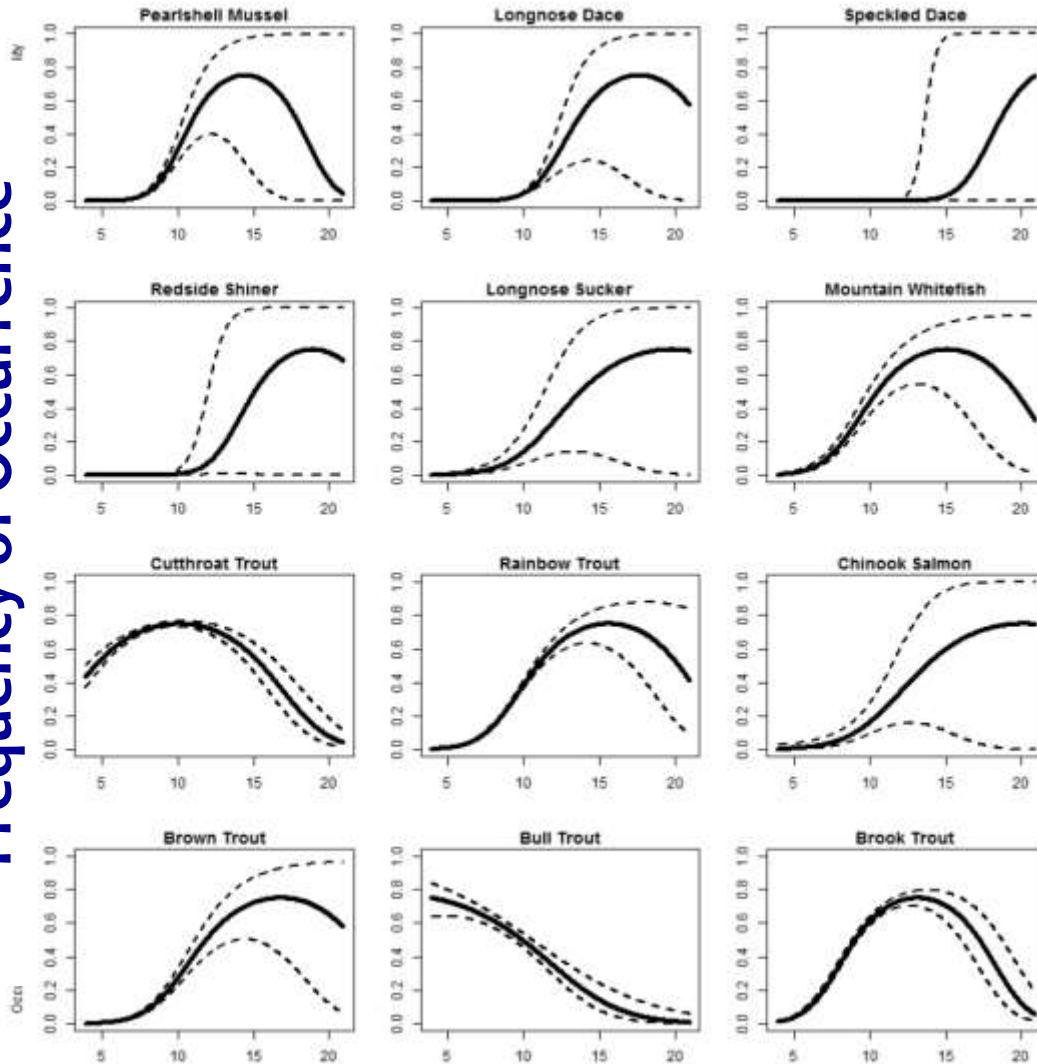
Just need georeferenced biological survey data



Too warm... Too cold... Just right

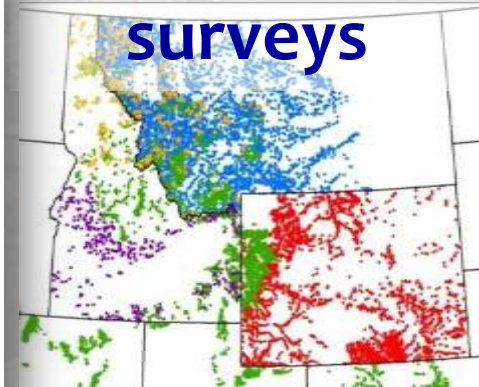
Thermal Niches in Batch Mode...

Frequency of Occurrence



NorWeST Stream Temperature (S1)

~13,000 fish surveys



More Accurate Species Distribution Models...

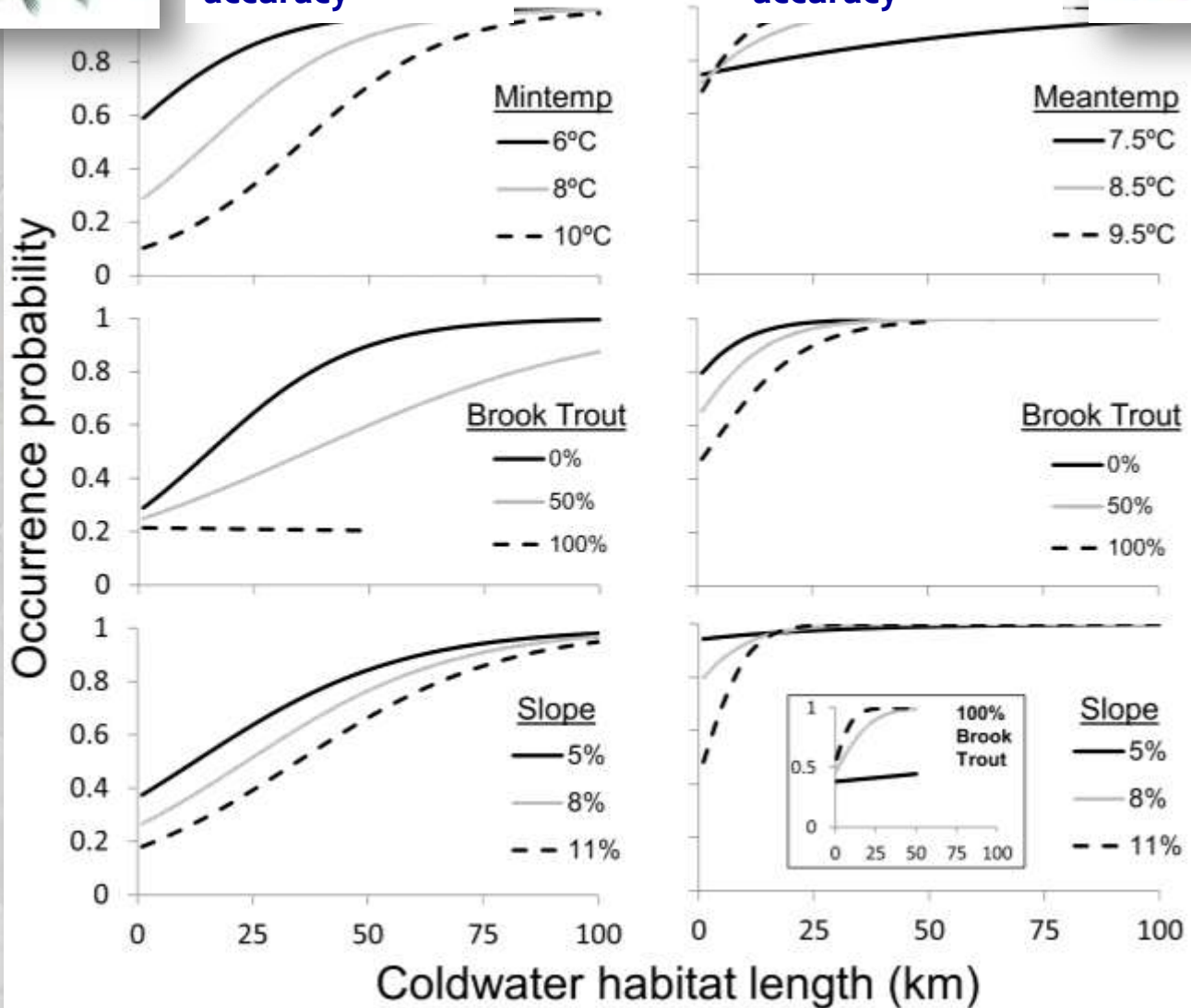
$$p = \frac{\exp(a + bx \dots ny)}{(1 + \exp[a + bx \dots ny])}$$



78% classification accuracy

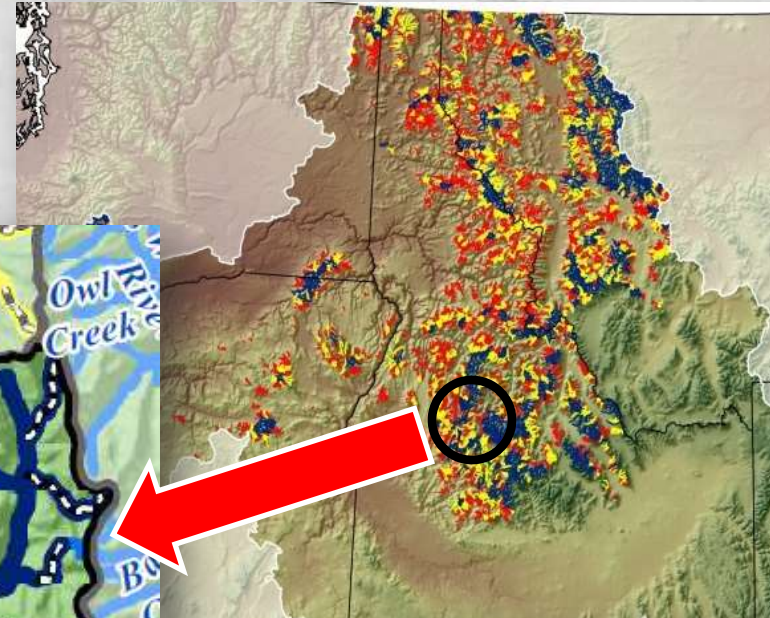
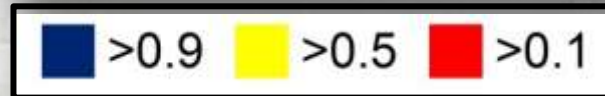


85% classification accuracy



Better Climate Vulnerability Assessments & Precise Mapping of Refuge Streams

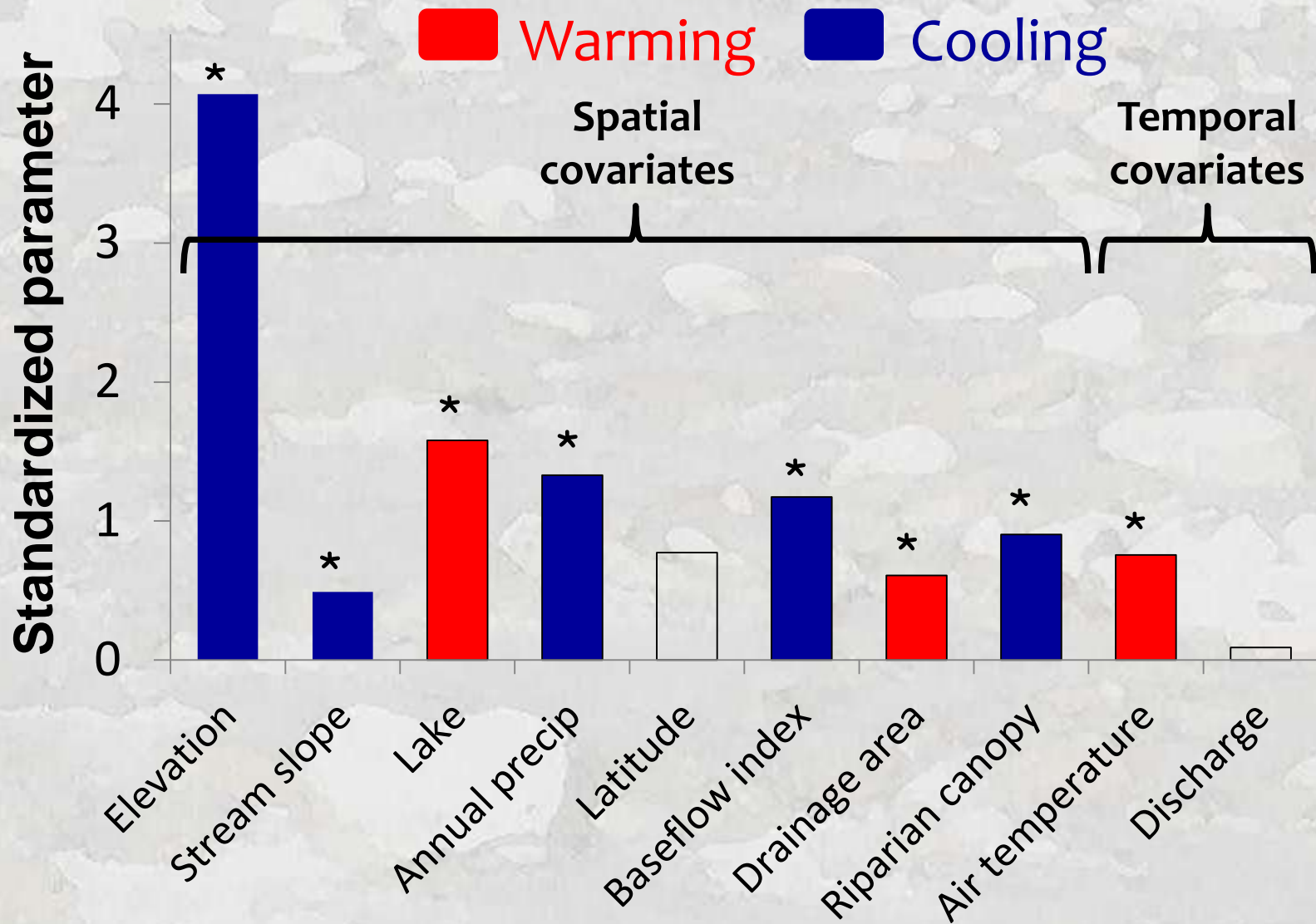
Occupancy Probability



Isaak et al. 2015. The cold-water climate shield: Delineating refugia for preserving native trout through the 21st Century. *Global Change Biology* 21 doi:10.1111/gcb

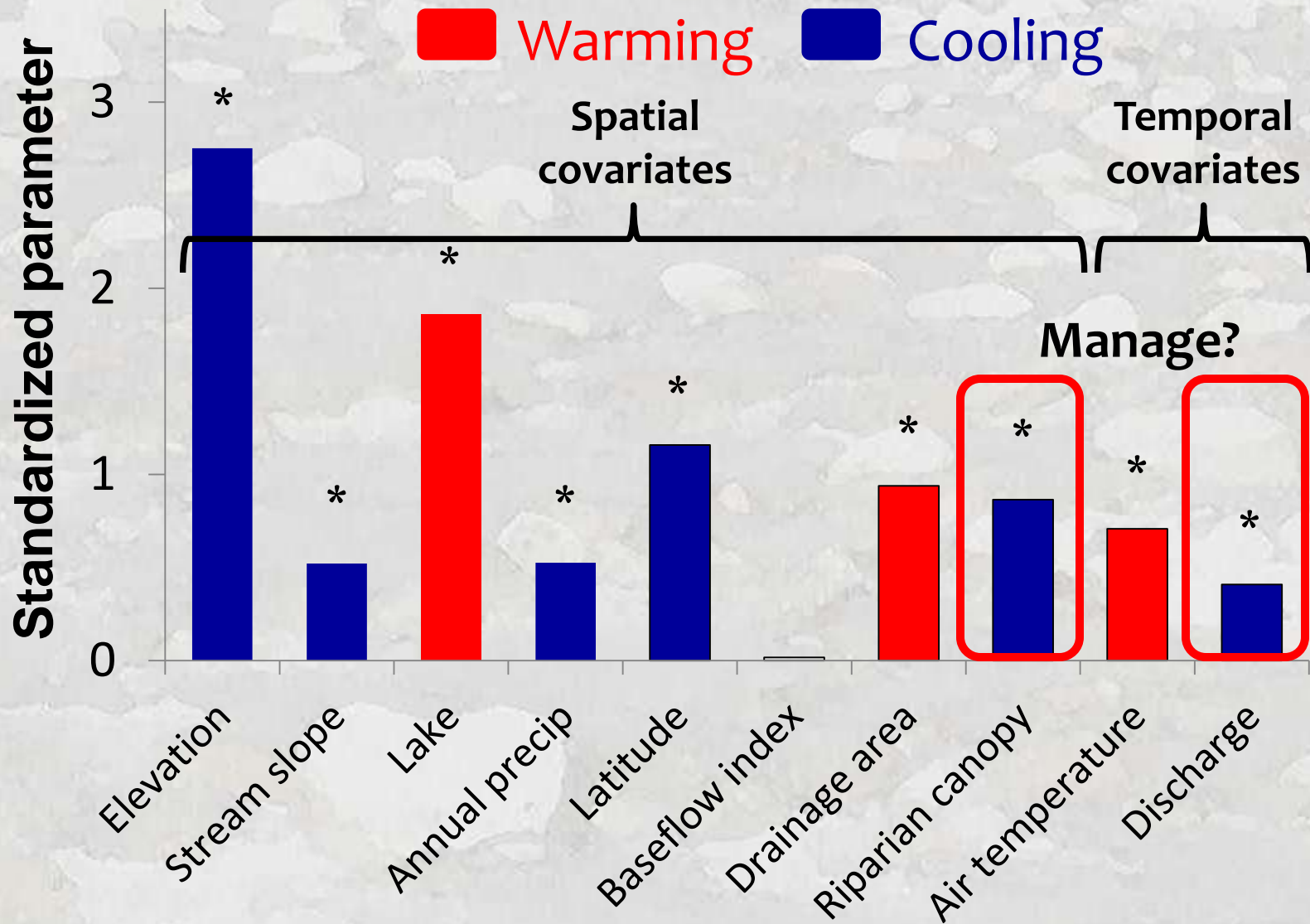
Relative Effects of Predictors

Mid-Columbia River Basin Model



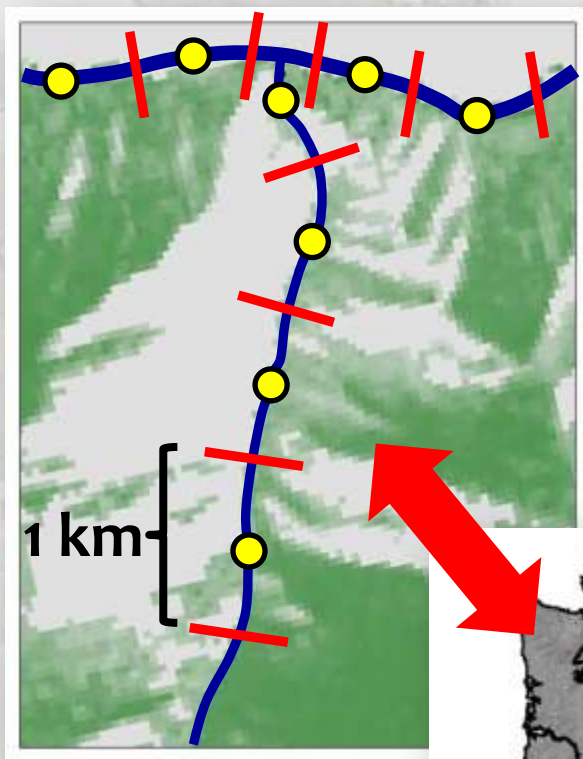
Relative Effects of Predictors

Northwest Montana Model

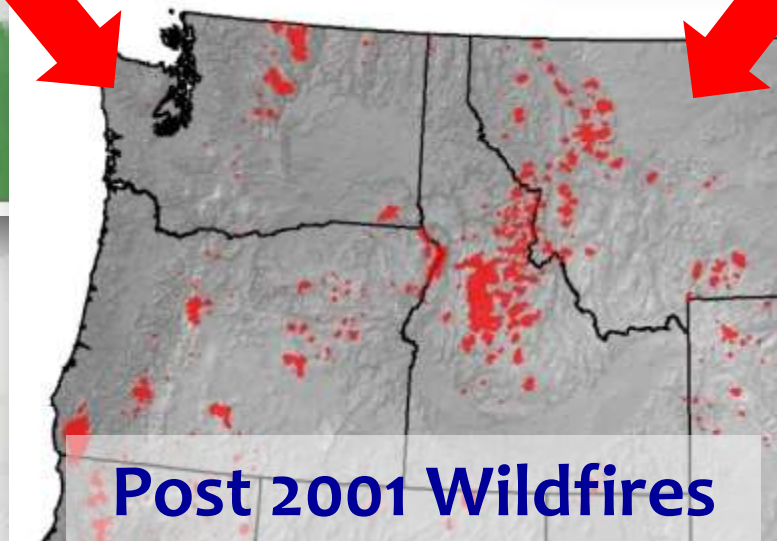
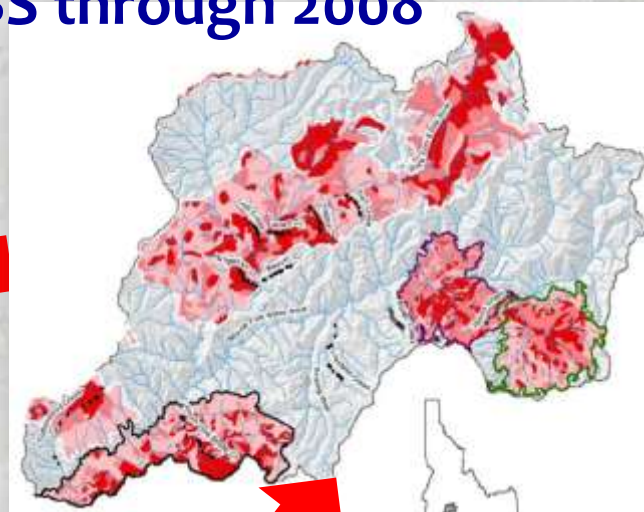


Riparian Canopy Predictor

%Canopy variable
from 2001 NLCD

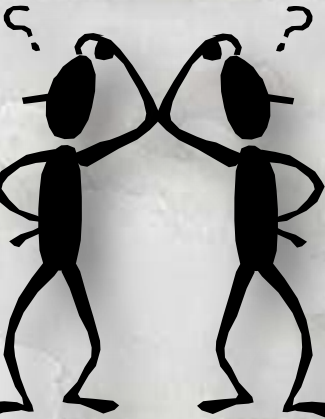
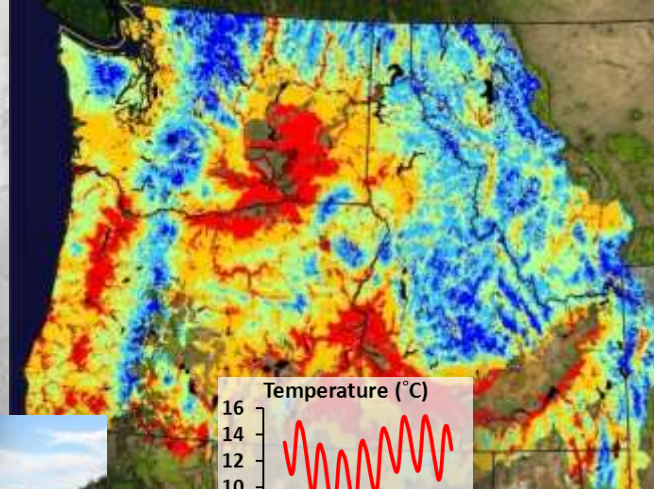


%Canopy adjusted by
MTBS through 2008



Natural vs Anthropogenic Effects

“Natural”

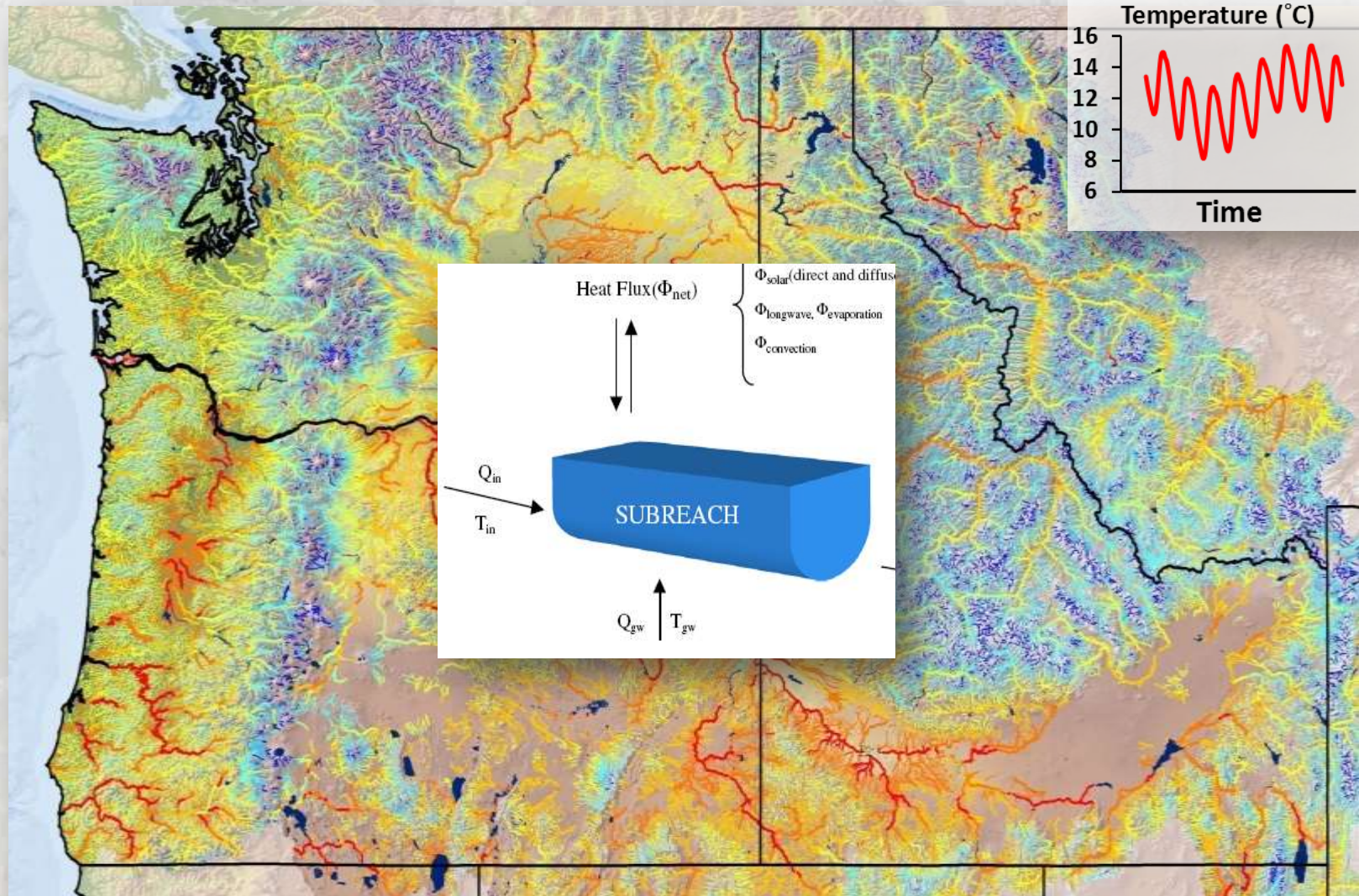


“Impaired”



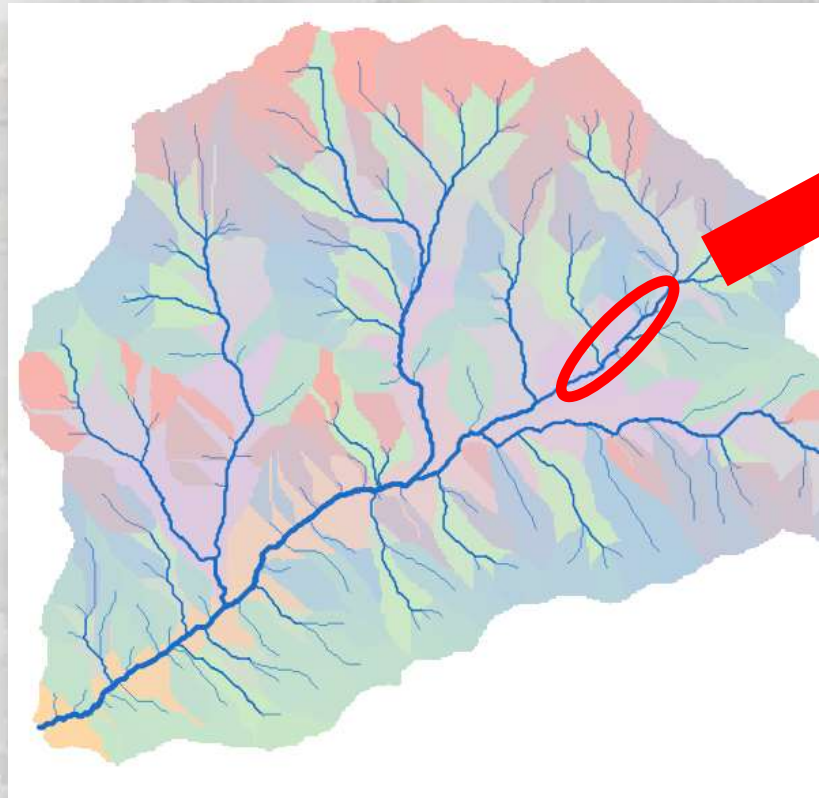
1. Nesting Mechanistic & Statistical Models

NorWeST provides boundary conditions



2. Additional Covariate Predictors

NHDPlus 1:100,000-Scale Streams



Reach

Descriptors:

- Elevation
 - Slope
 - %Landuse
 - Precipitation
- 100's more...**

- Precise measures of local impairment
- Scale-able to other areas?

2. Additional Covariate Predictors

Best candidates...

Local stream radiation estimates (hemispherical photography/LiDAR surveys of current conditions... **but site potential also needed**)

Local flow estimates (current/potential under different climate/water use scenarios)

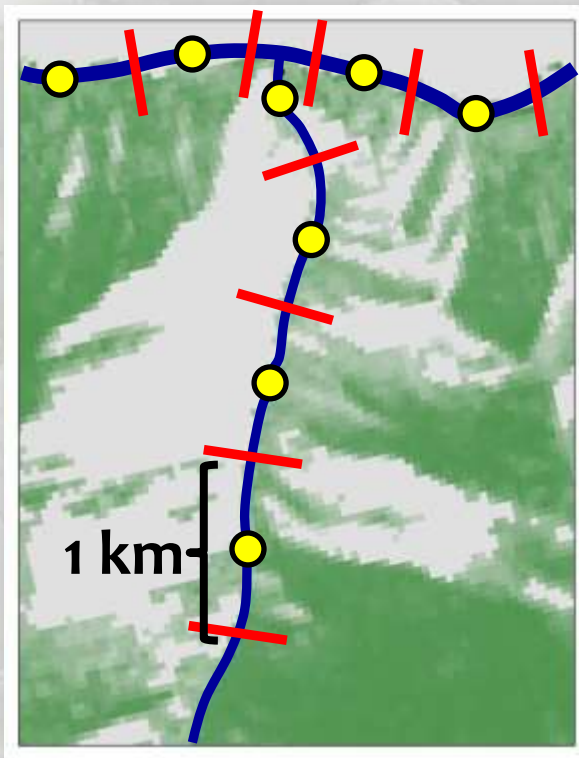
Local channel morphology estimates (current/potential conditions if fully restored)

... **non-trivial tasks**

2. Additional Covariate Predictors

An example...

NLCD Canopy%



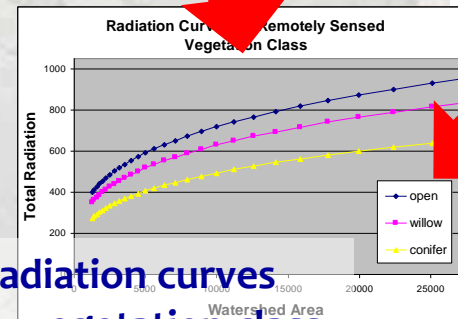
vs.

Detailed hemispherical photos & radiation estimates

Canopy Photography



TM satellite imagery



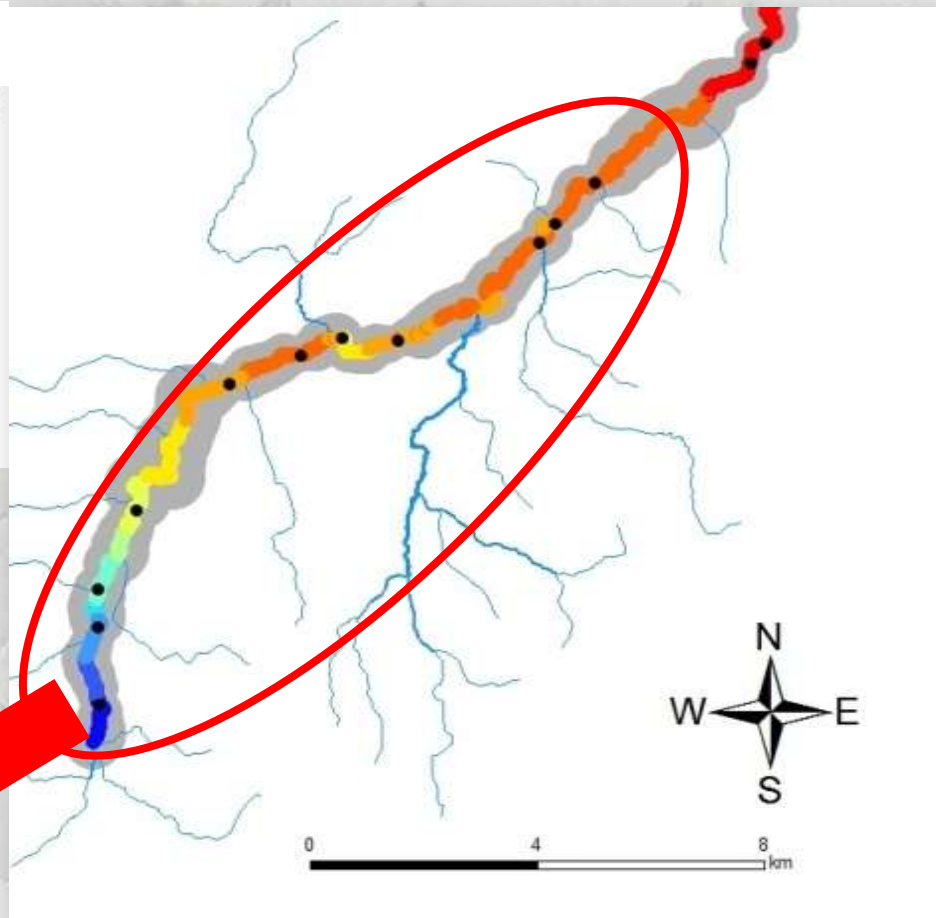
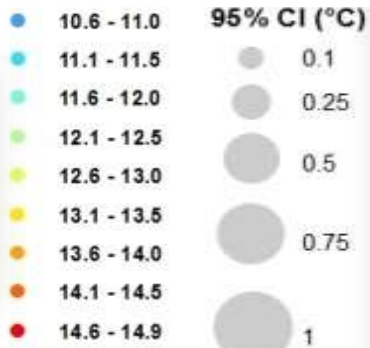
Radiation curves by vegetation class

Isaak et al. 2010. *Ecol. Apps* 20:1350-1370.

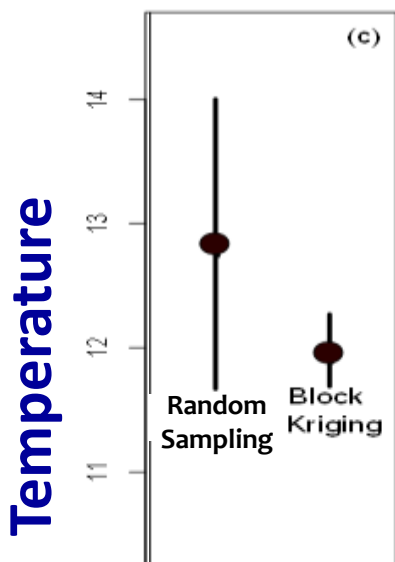
3. Block-krige Estimates of Mean & Variance at User-Defined Scale



Temperature (°C)



Bear Valley Creek Mean Temperature



} Precise & unbiased estimates

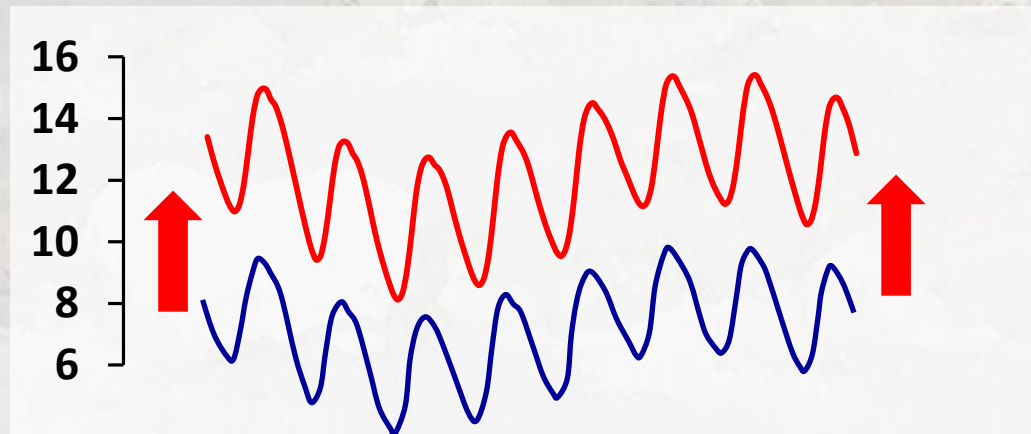
Does this reach meet the TMDL standard?

Reference Site Comparison Approach

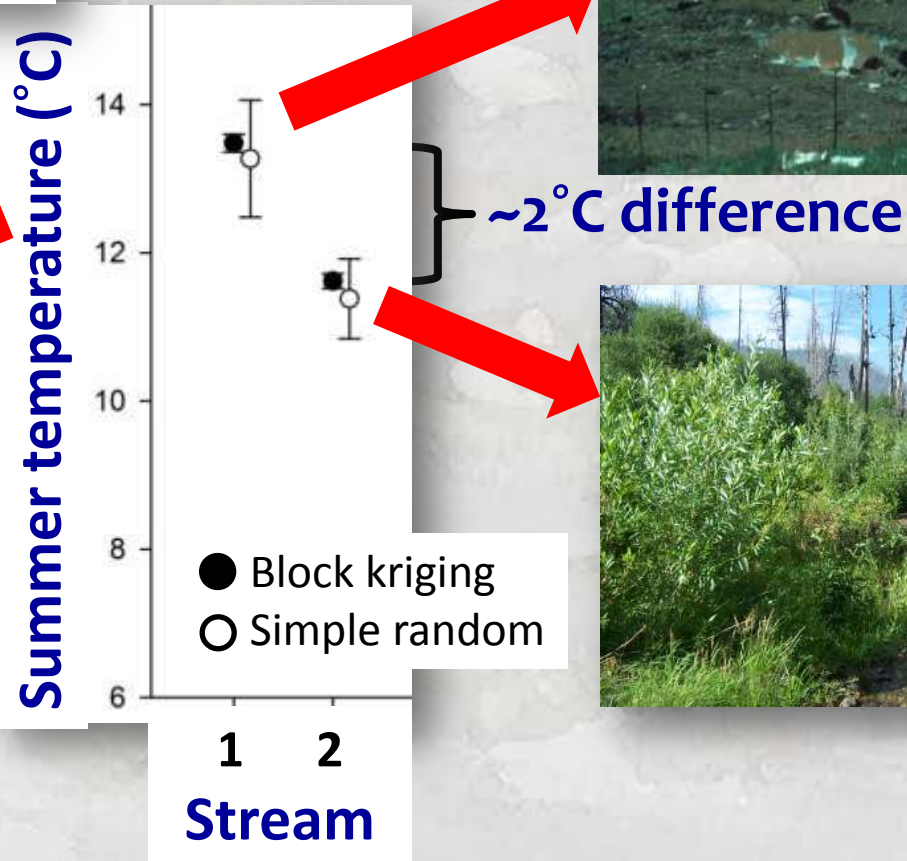
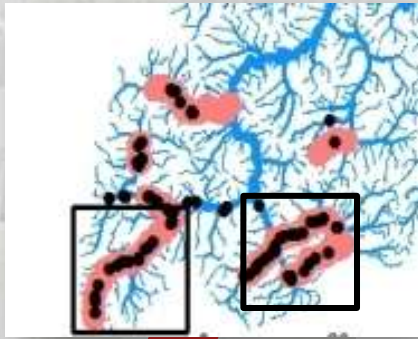
Pick “impaired” & “natural” streams to compare



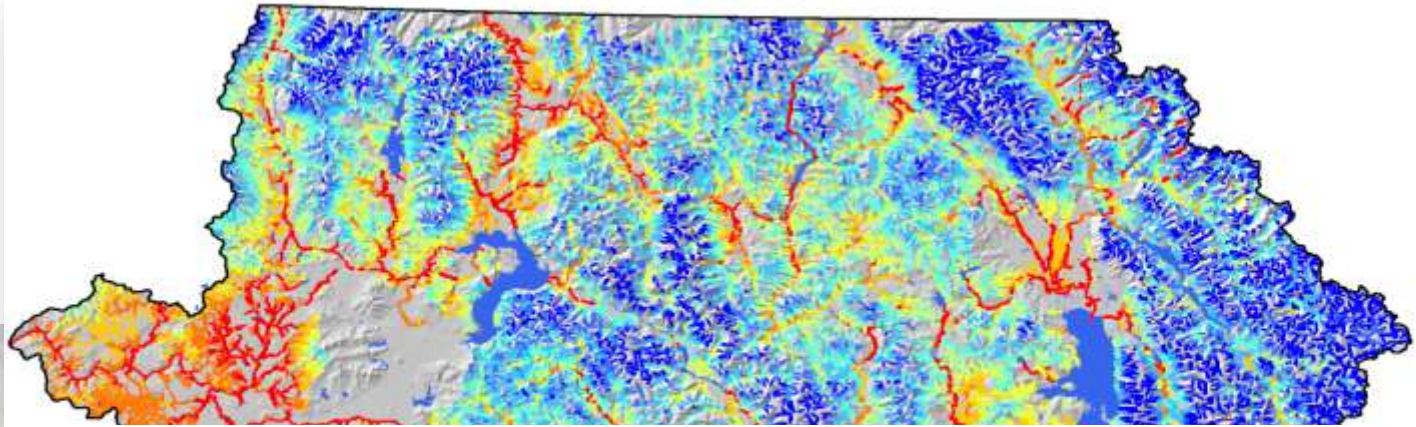
How altered is this stream?



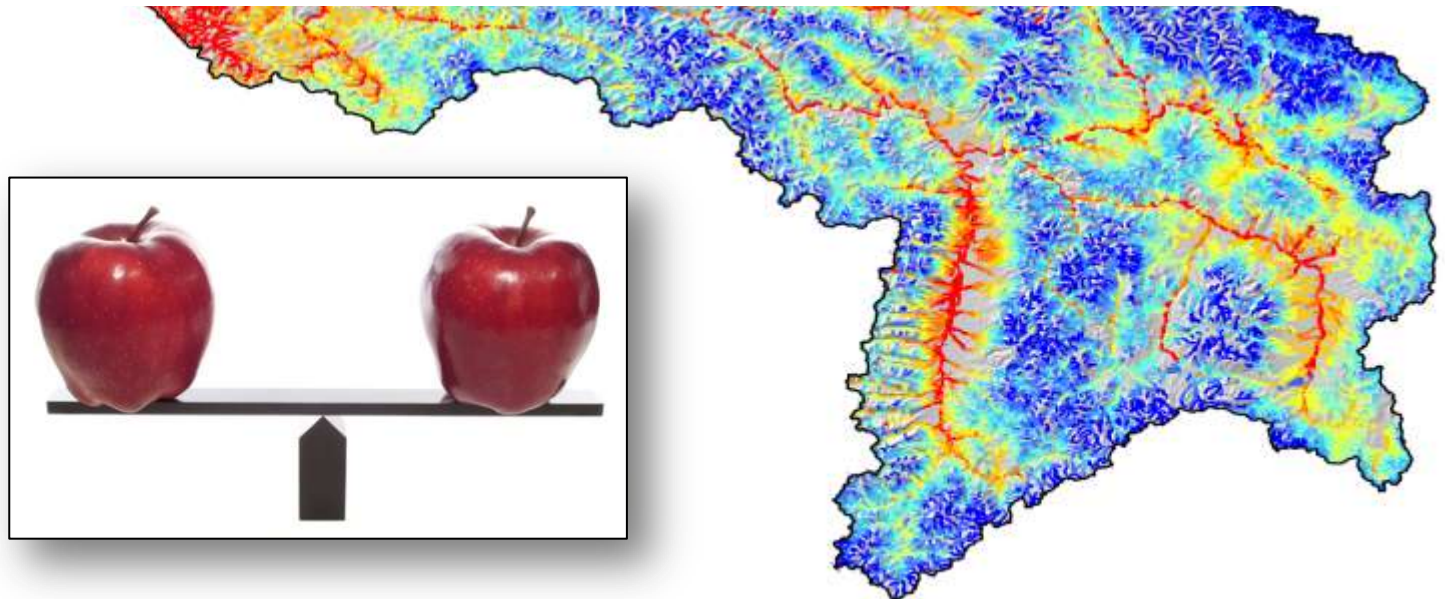
Block-Krige Estimates for Both Streams



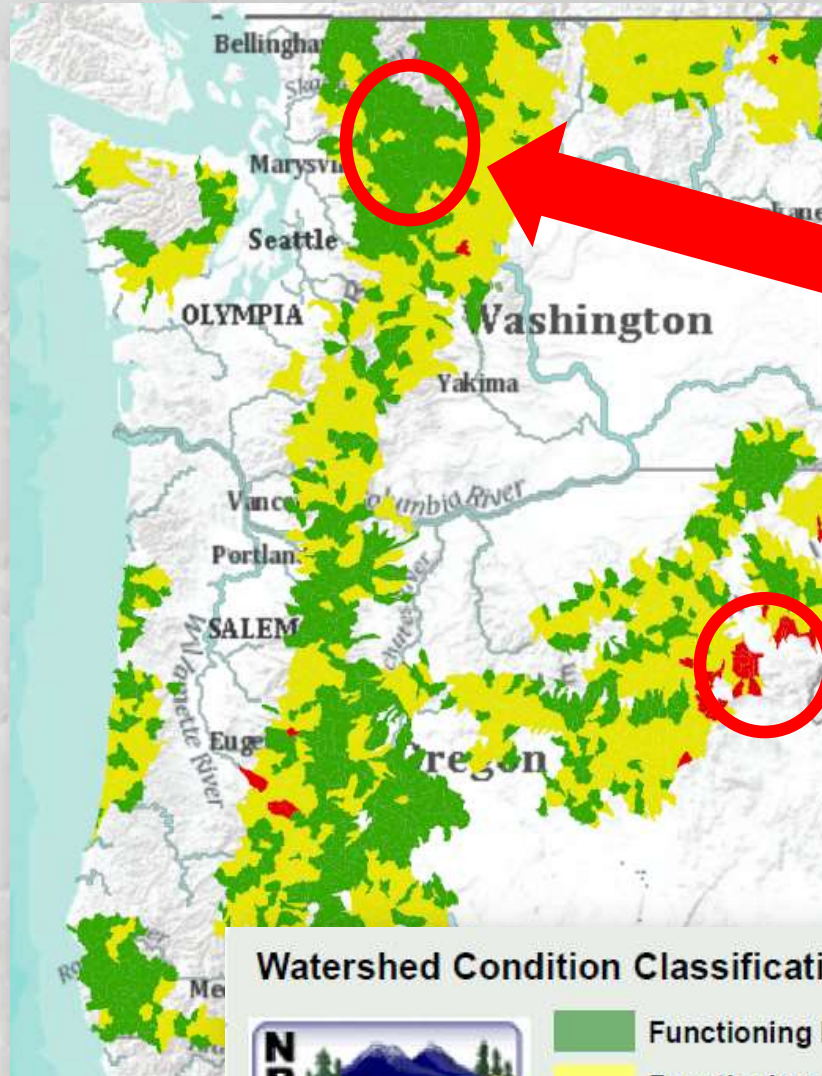
Block-Krige Estimates for Both Streams



Do so anywhere within a river network



Reference Site Approach Requires Good Watershed/reach Classifications



Reference



Impaired



Watershed Condition Classification



- Functioning Properly
- Functioning at Risk
- Impaired Function

Block-Kriging & Reference Site Approach Broadly Applicable for Many Water Parameters...

Sediment...



Urban runoff...



Nutrients...

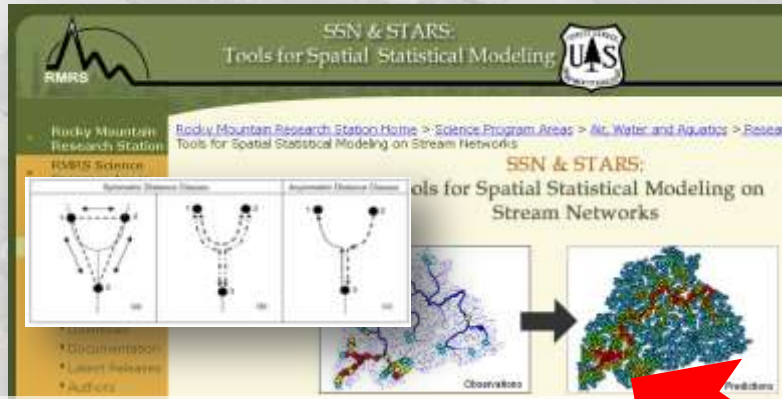


Mining...

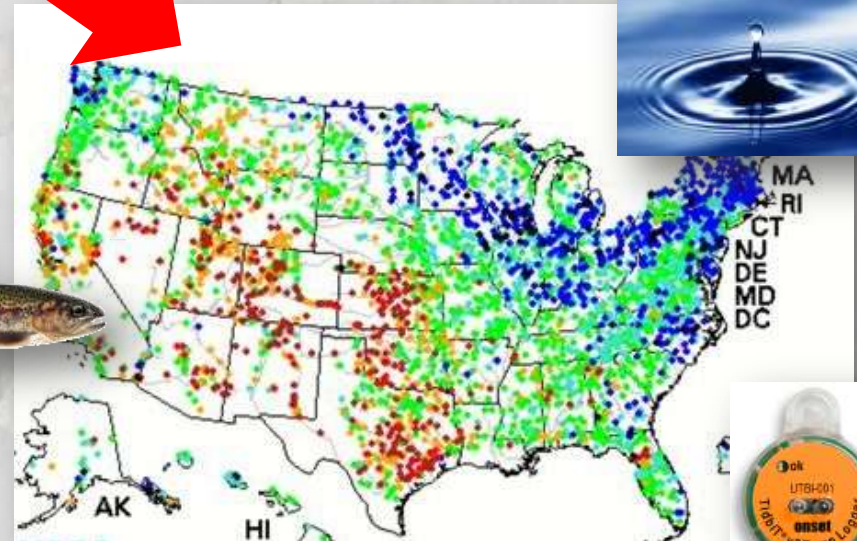


Many Powerful New Tools & Datasets

SSN/STARS Website



- Software
- Example Datasets
- Documentation



The Grail is Within our Grasp...

Better information = better understanding & prediction

