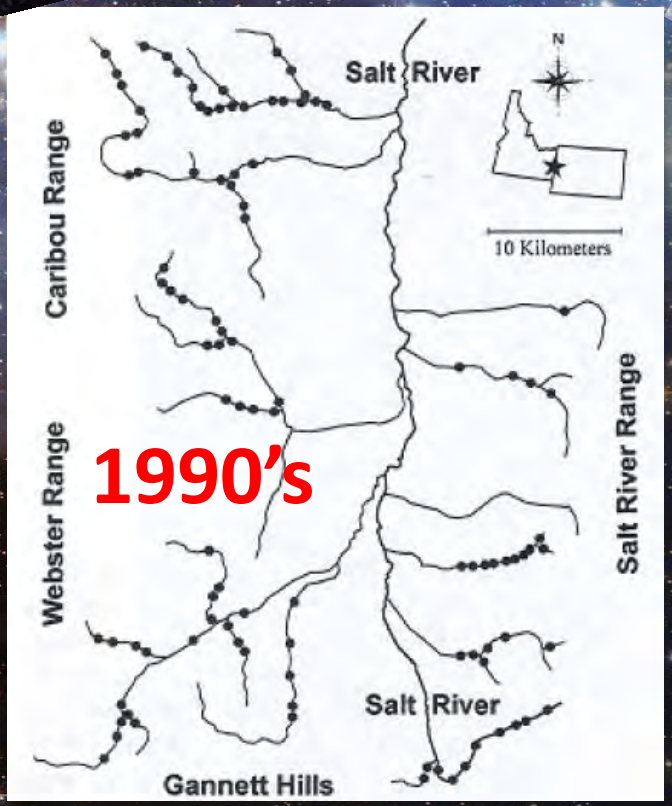
Space…The final stream frontier

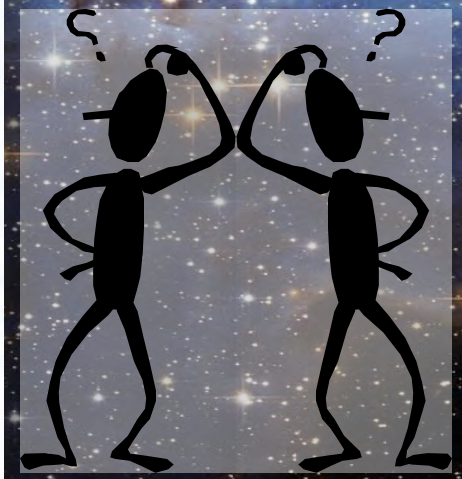
Ecology, 74(6), 1993, pp. 1659–1673

SPATIAL AUTOCORRELATION: TROUBLE OR NEW PARADIGM?[1]

PIERRE LEGENDRE
Département de sciences biologiques, Université de Montréal, C.P. 6128, succursale A, Montréal, Québec, Canada H3C 3J7



1990's



Spatial Statistical Models for Stream Networks!

Environ Ecol Stat (2006) 13:449–464
DOI 10.1007/s10651-006-0022-8

ORIGINAL ARTICLE

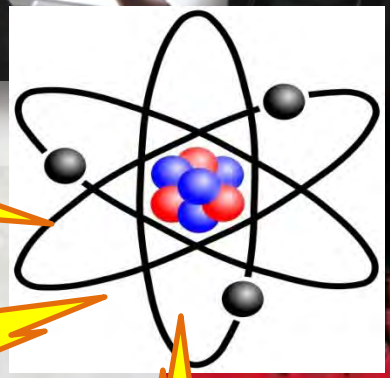
Spatial statistical models that use flow and stream distance

Jay M. Ver Hoef · Erin Peterson · David Theobald

Freshwater Biology (2007) 52, 267–279 doi:10.1111/j.1365-

Geostatistical modelling on stream networks: developing valid covariance matrices based on hydrologic distance and stream flow

ERIN E. PETERSON,* DAVID M. THEOBALD† AND JAY M. VER HOEF‡



Functional Linkage of Water basins and Streams (FLoWS) v1 User's Guide:

ArcGIS tools for Network-ba

Contact info:

Authors:
David M. Theobald
John B. Norman
E. Peterson
S. Ferraz
A. Wade
M.R. Sherburne

Spatial modelling and prediction on river networks: up model, down model or hybrid?

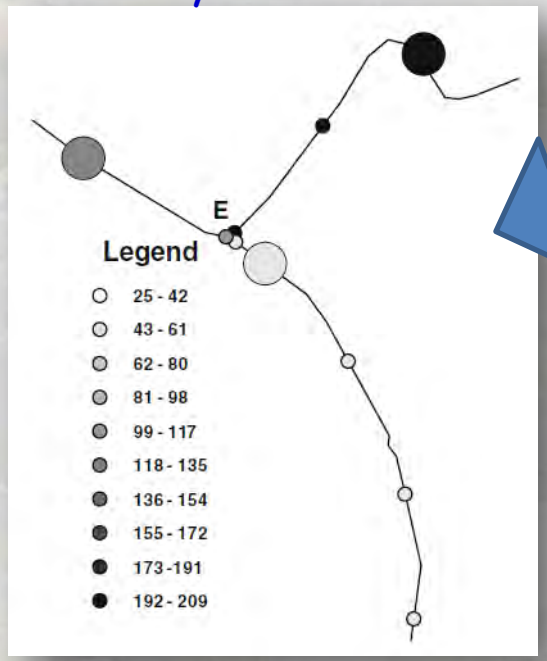
Vincent Garreta[1*,†], Pascal Monestiez[2] and Jay M. Ver Hoef[3]

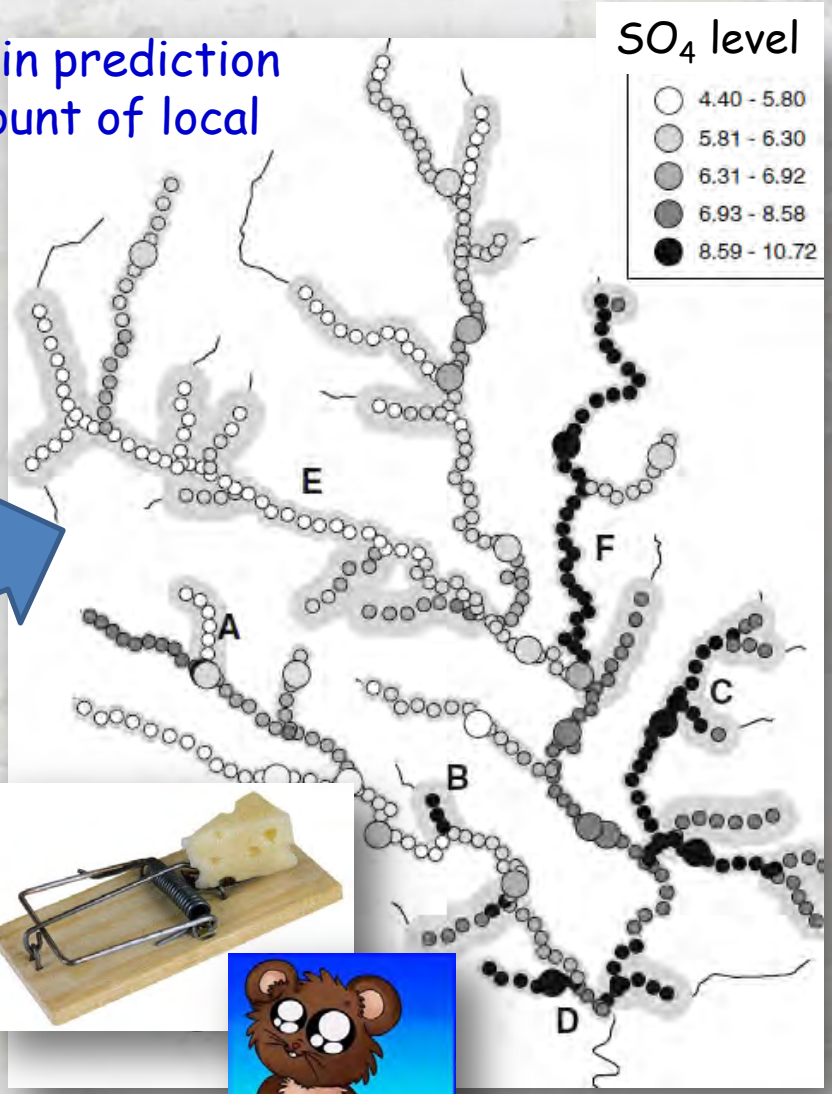
[1]*CEREGE, UMR 6635, CNRS, Université Aix-Marseille, Europôle de l'Arbois, 13545 Aix-en-Provence, France*
[2]*INRA, Unité de Biostatistique et Processus spatiaux, Domaine St Paul, Site Agroparc, 84914 Avignon Cedex 9, France*
[3]*NOAA National Marine Mammal Lab, Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115, USA*

Spatial Statistical Network Models Work the Way that Streams Do…

Portray spatial differences in prediction precision related to the amount of local empirical support…

…& represent changes in attributes that occur at tributary confluences

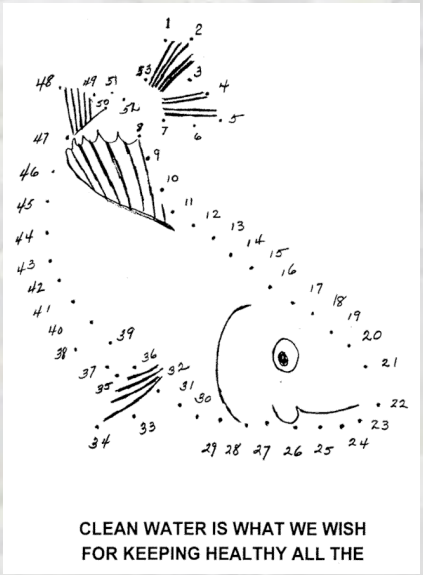


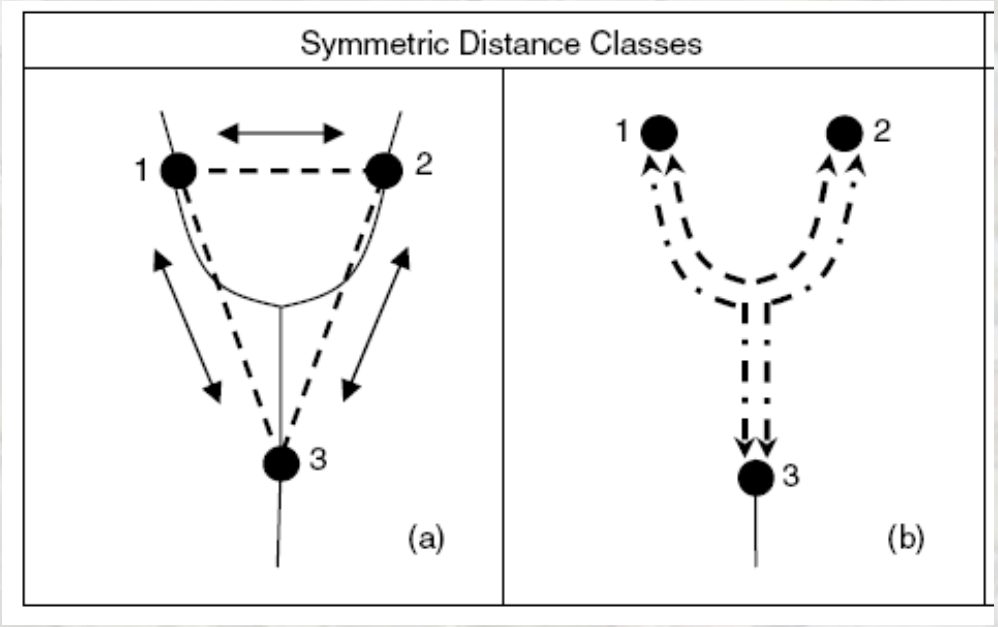


…& are significantly better mousetraps

Valid interpolation on networks—finally!

Spatial Statistical Models are Dot Connectors



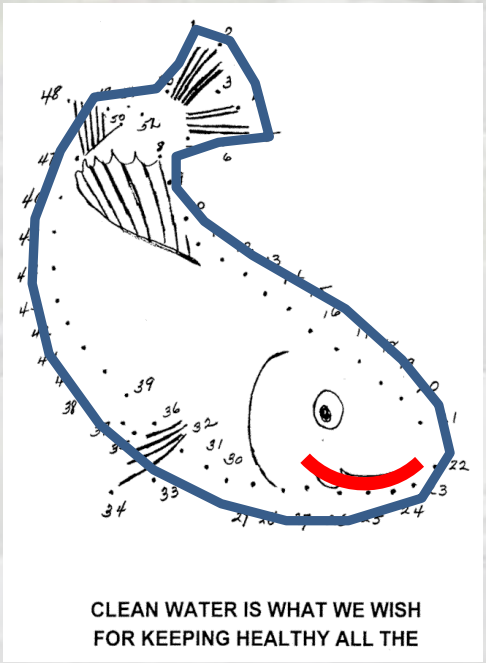


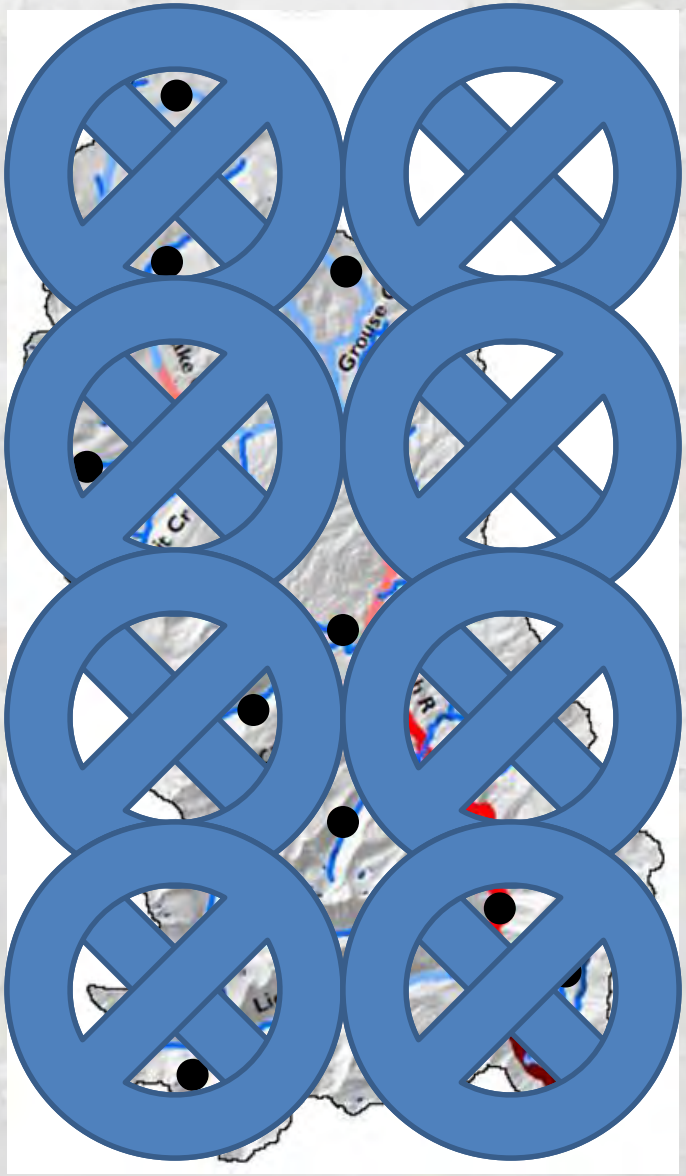
Advantages:

- -flexible & valid covariance structures by accommodating network topology
- -weighting by stream size
- -improved predictive ability & parameter estimates relative to non spatial models

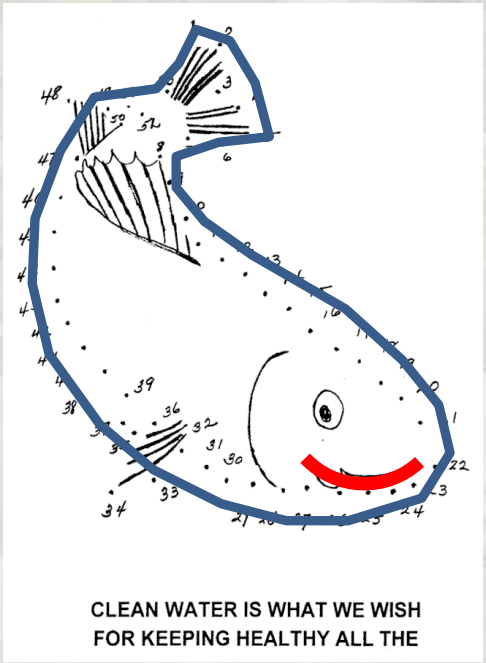
Peterson et al. 2006; Ver Hoef et al. 2006; Ver Hoef and Peterson 2010

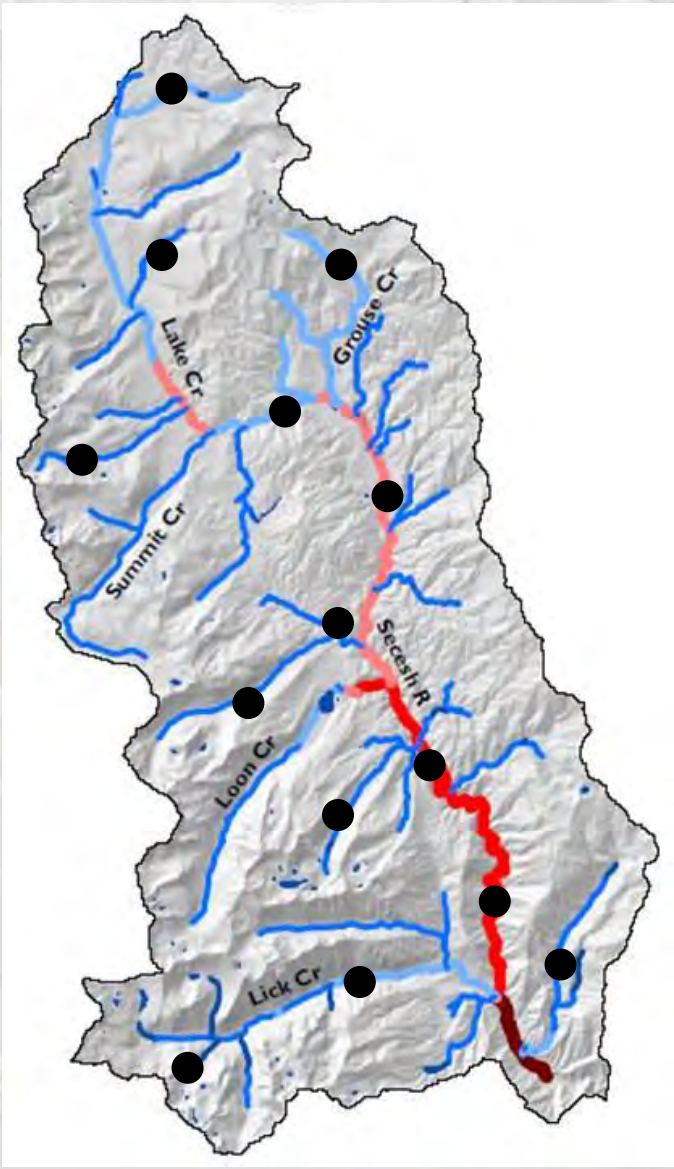
Stop Viewing Streams as Dots





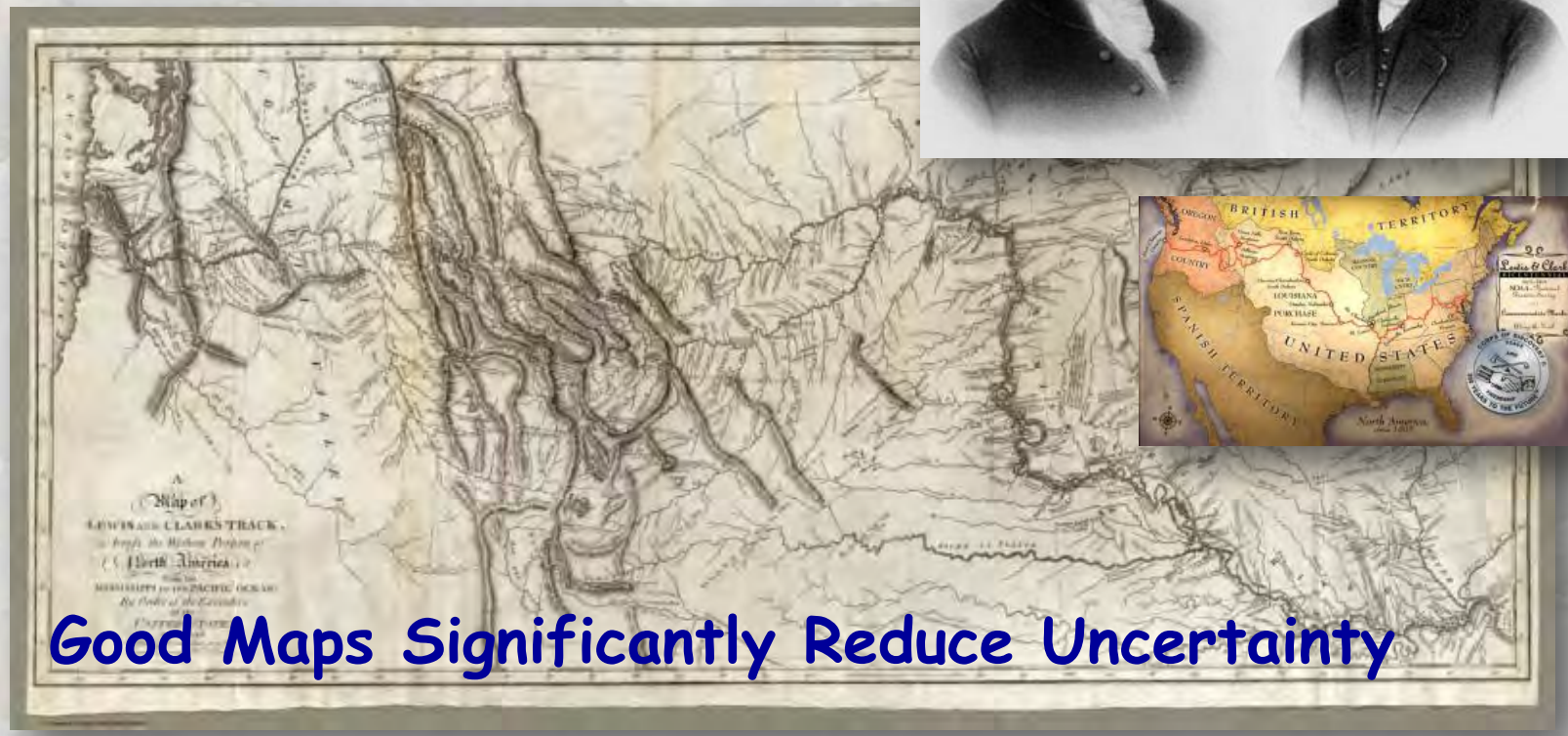
Stop Viewing Streams as Dots





"Smart" Maps Developed from Data to Show Resource Status & Guide Efficient Monitoring Design

There's an inefficient army running around…

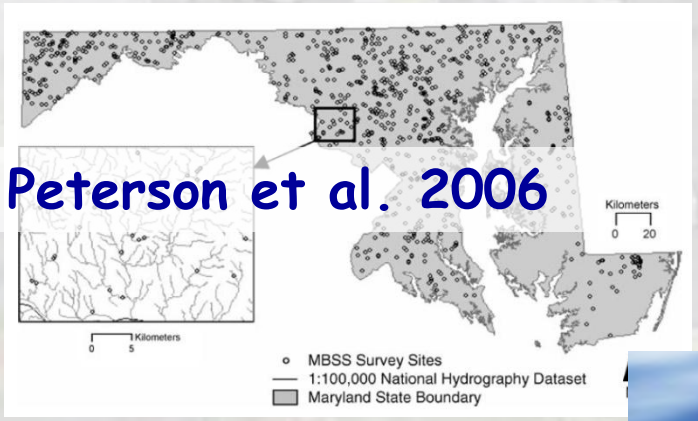


Good Maps Significantly Reduce Uncertainty

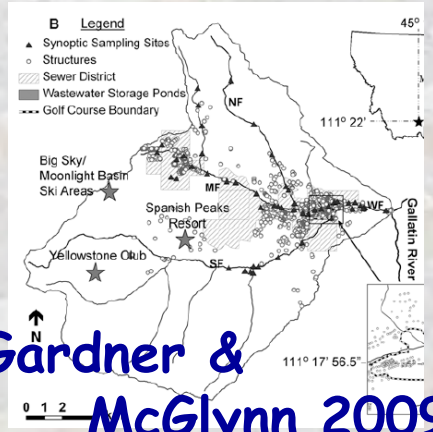
Harnessing Existing Databases

Water Quality/Chemistry Information

(Nitrates, alkalinity, ph, DOC, conductivity, etc.)

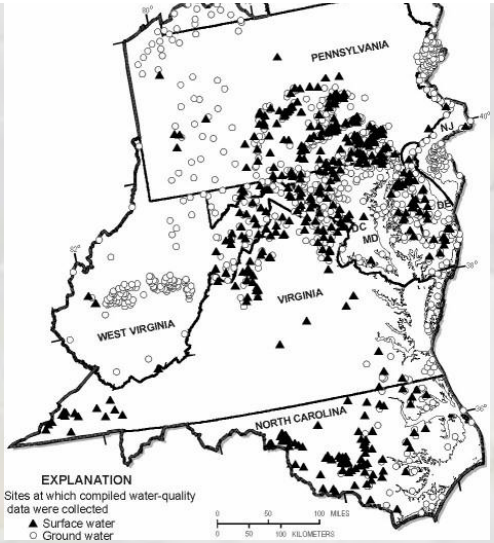


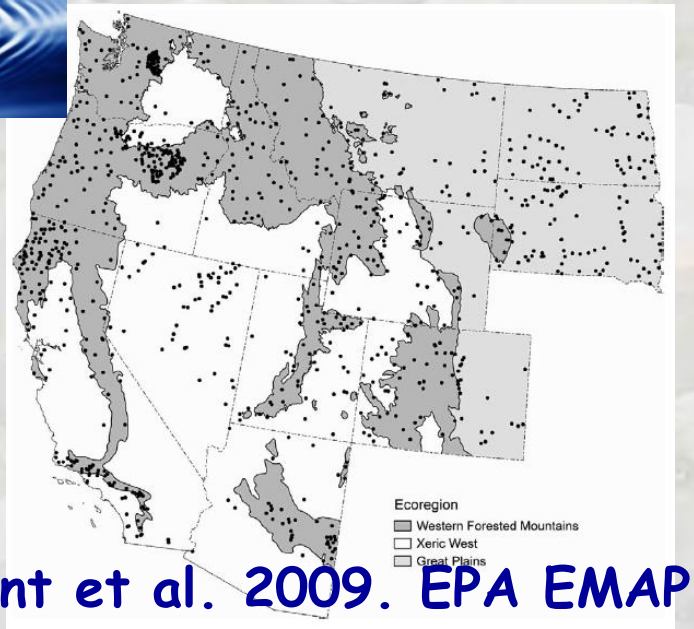
Peterson et al. 2006



Gardner & McGlynn 2009

USGS, unpublished



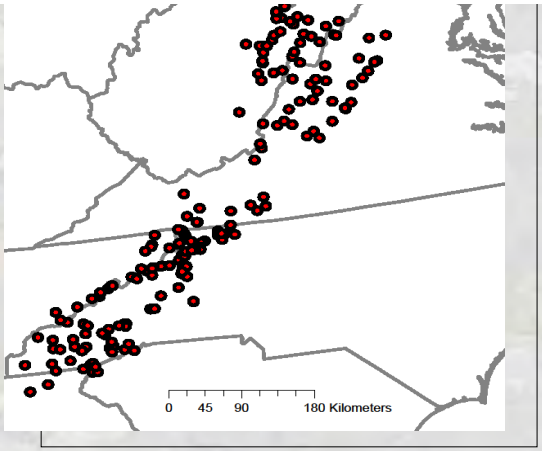


Pont et al. 2009. EPA EMAP

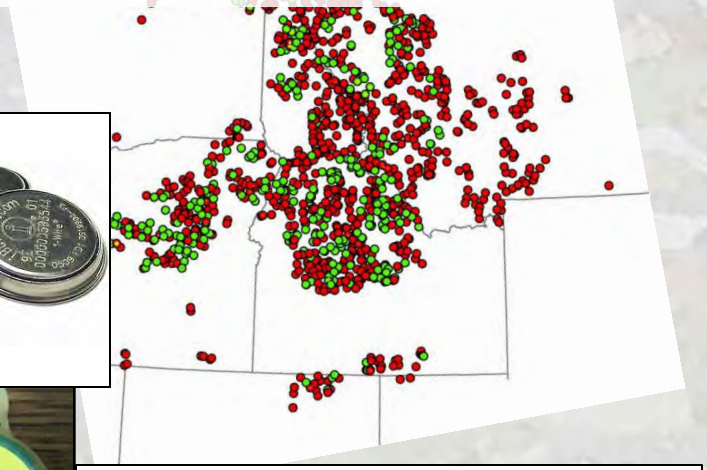
Harnessing Existing Databases

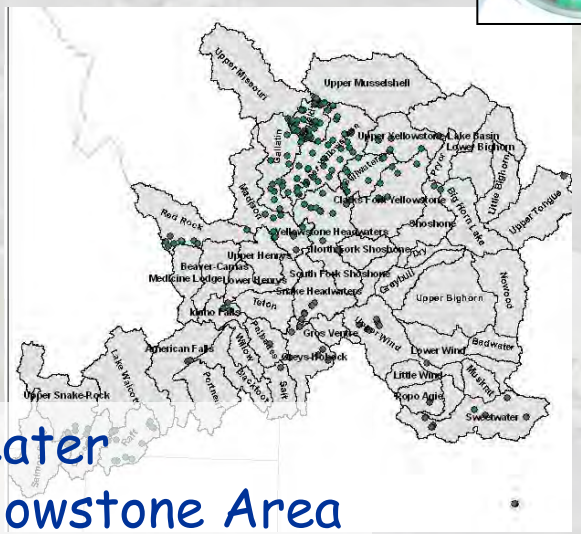
Stream Temperature Information

Eastern Brook Trout Temp Sensor (n ~ 200)

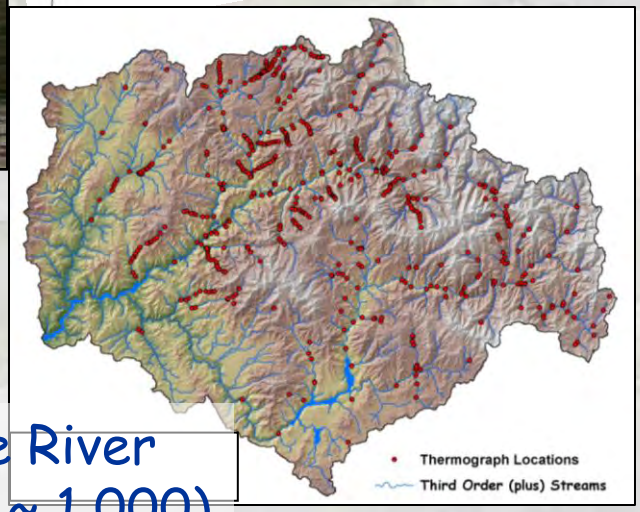


USFS PIBO data (n ~ 3000)





Greater Yellowstone Area

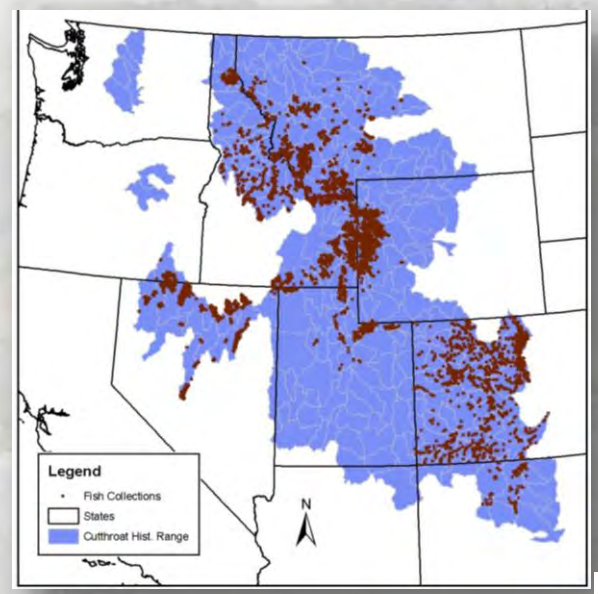


Boise River (n ~ 1,000)

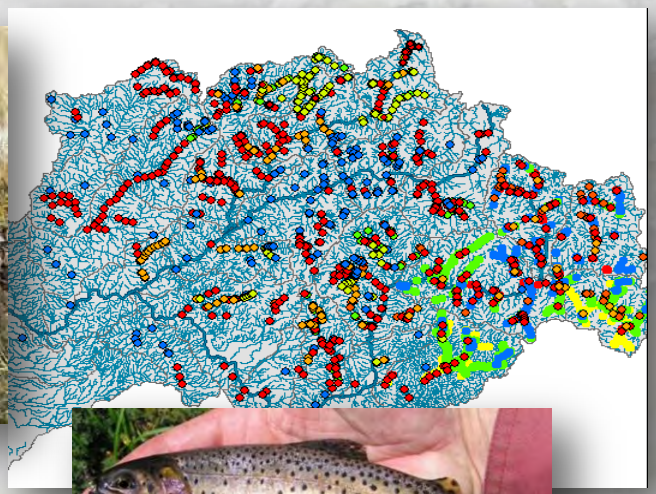
Harnessing Existing Databases

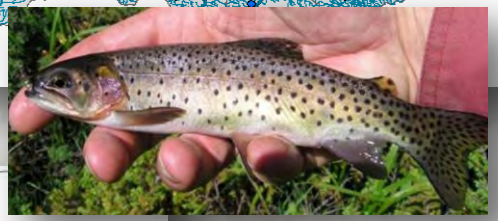
Distribution & abundance of critters

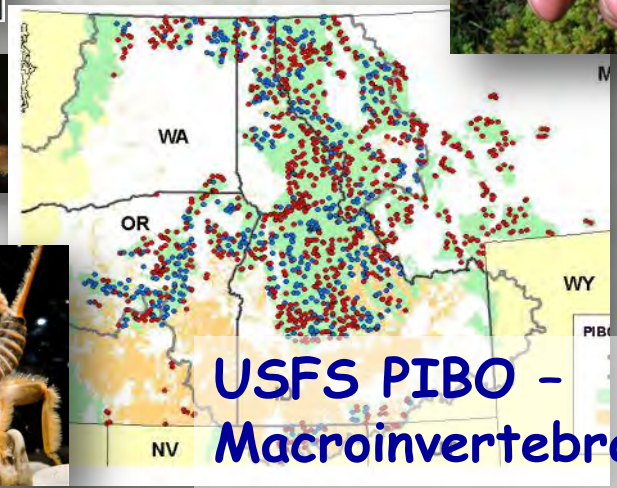
Cutthroat Trout
Fish database (n ~ 10,000)



Boise basin fish
database (n ~ 2,000)



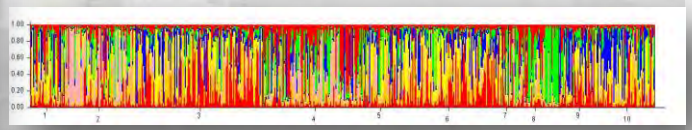




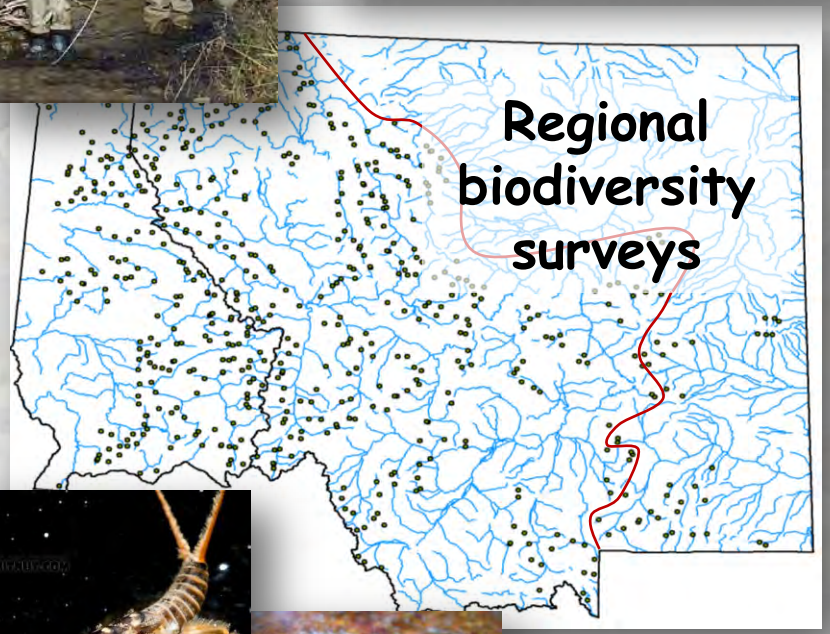
USFS PIBO - Macroinvertebrates (n ~ 2,500)

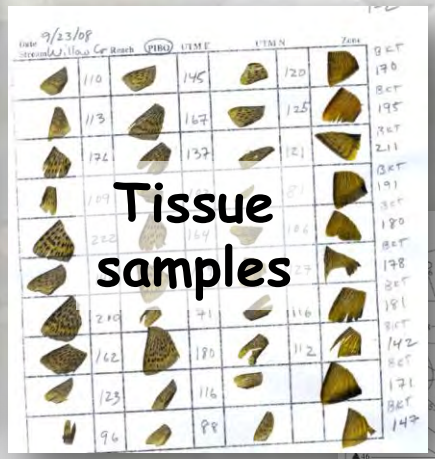
Lots of genetic data coming…

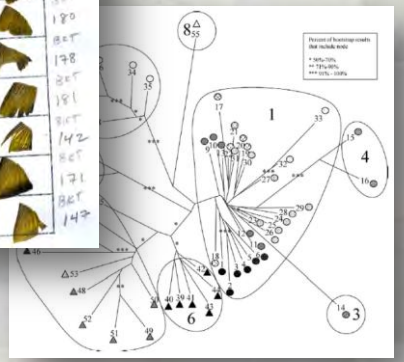
DNA Barcoding…



- Inexpensive SNP technology ($5/fish)
- Maps of genetic diversity
- New species descriptions



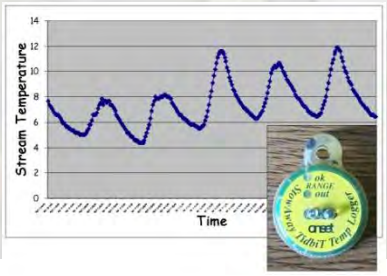


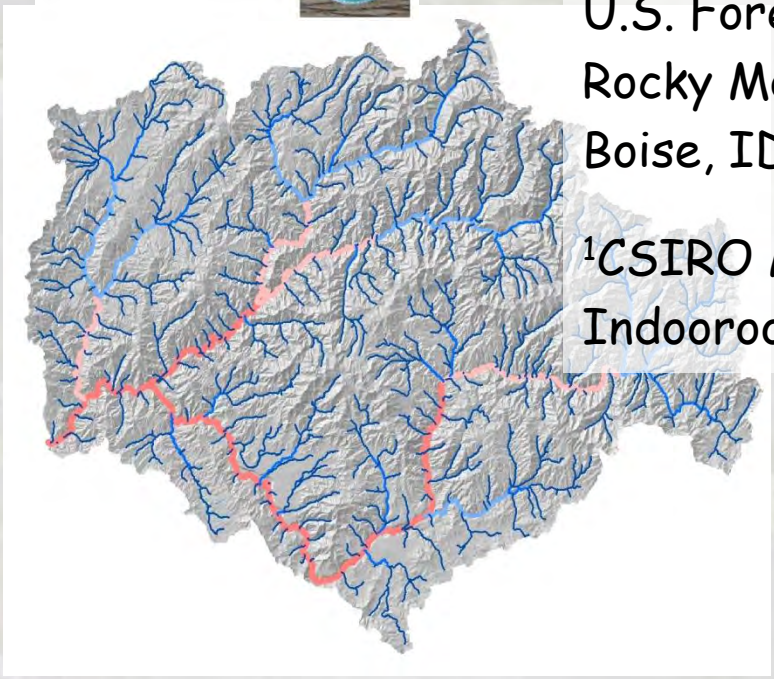


Genetic monitoring as a promising tool for conservation and management

Michael K. Schwartz[1], Gordon Luikart[2,3] and Robin S. Waples[4]

Boise River Application to Develop a River Network Temperature Model





Dan Isaak, Charlie Luce, Bruce Rieman, Dave Nagel, Erin Peterson[1], Dona Horan, Sharon Parkes, and Gwynne Chandler

Boise Aquatic Sciences Lab
U.S. Forest Service
Rocky Mountain Research Station
Boise, ID 83702

[1]CSIRO Mathematical and Information Sciences
Indooroopilly, Queensland, Australia

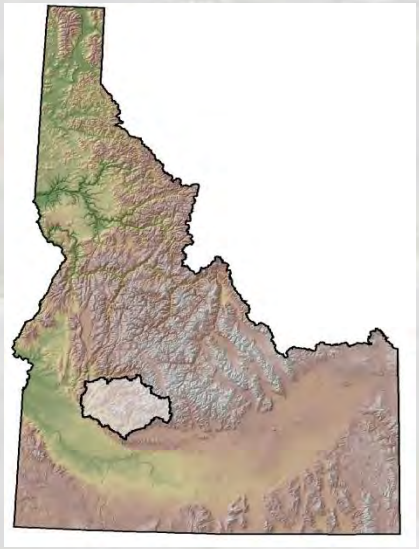
CSIRO

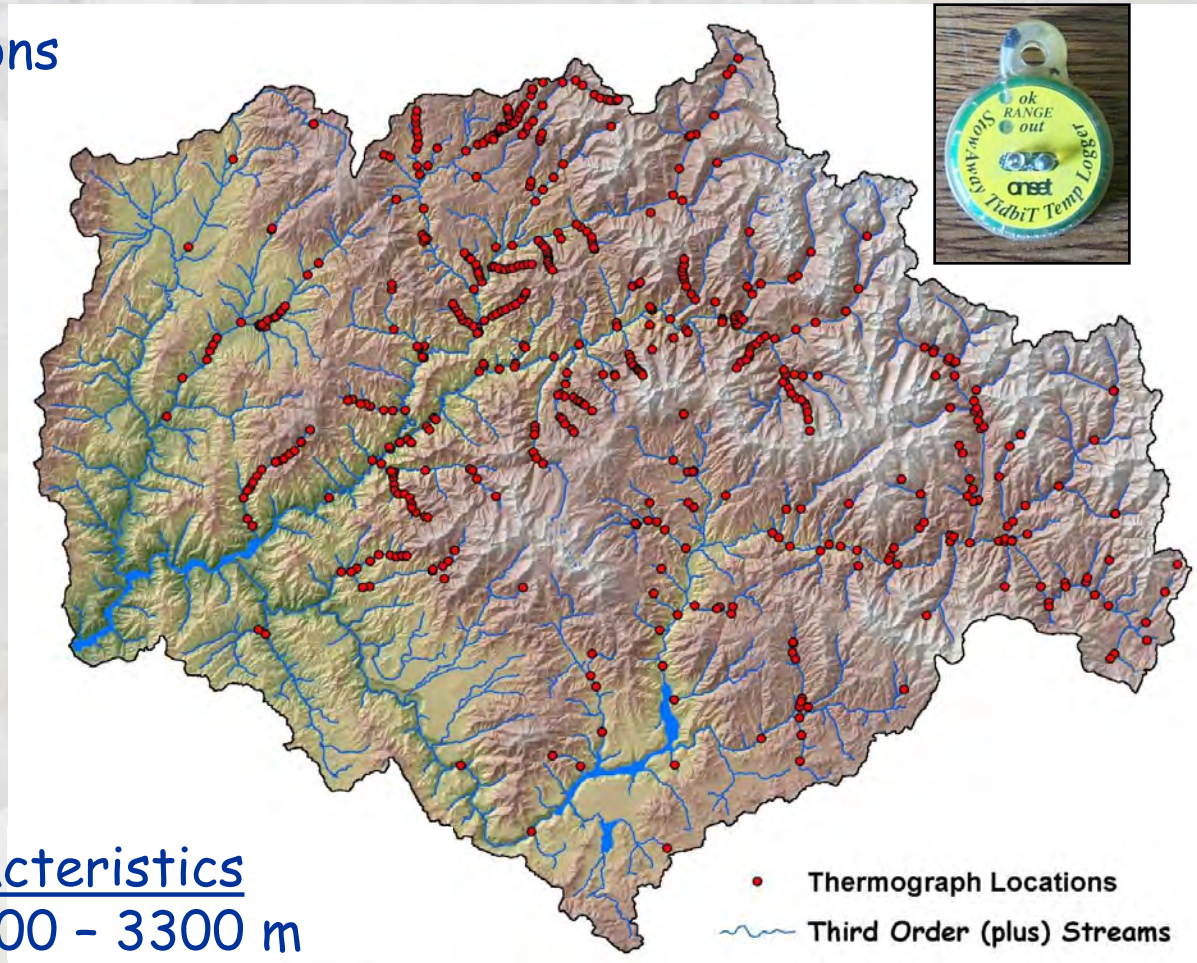
BOISE AQUATIC SCIENCES LAB
RMRS

Boise River Temperature Database

Stream Temperature Database

14 year period (1993 – 2006)
780 observations
518 unique locations





Watershed Characteristics

Elevation range 900 – 3300 m
Fish bearing streams ~2,500 km
Watershed area = 6,900 km^2

Training on left 2007 validation on right Data from 200

Boise River Temperature Models

Summer Mean

Non-spatial Stream Temp =
- 0.0064*Elevation (m)
+ 0.0104*Radiation
+ 0.39*AirTemp (°C)
- 0.17*Flow (m^3/s)

Parameter estimates are different because of autocorrelation in database

Spatial Stream Temp =
- 0.0045*Elevation (m)
+ 0.0085*Radiation
+ 0.48*AirTemp (°C)
- 0.11*Flow (m^3/s)

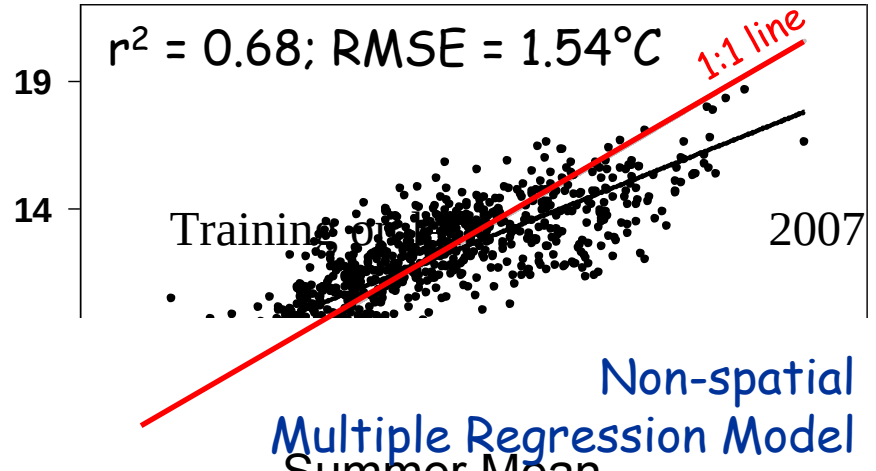
Predicted (C°)

MWMT

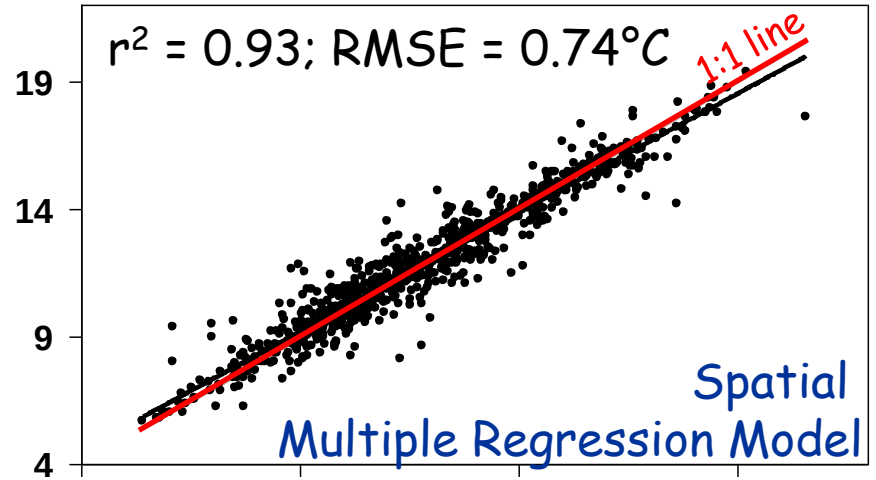
Isaak et al. 2010. *Ecol. Apps.* 20:1350-1371

Mean Summer Stream Temp

Summer Mean



Summer Mean

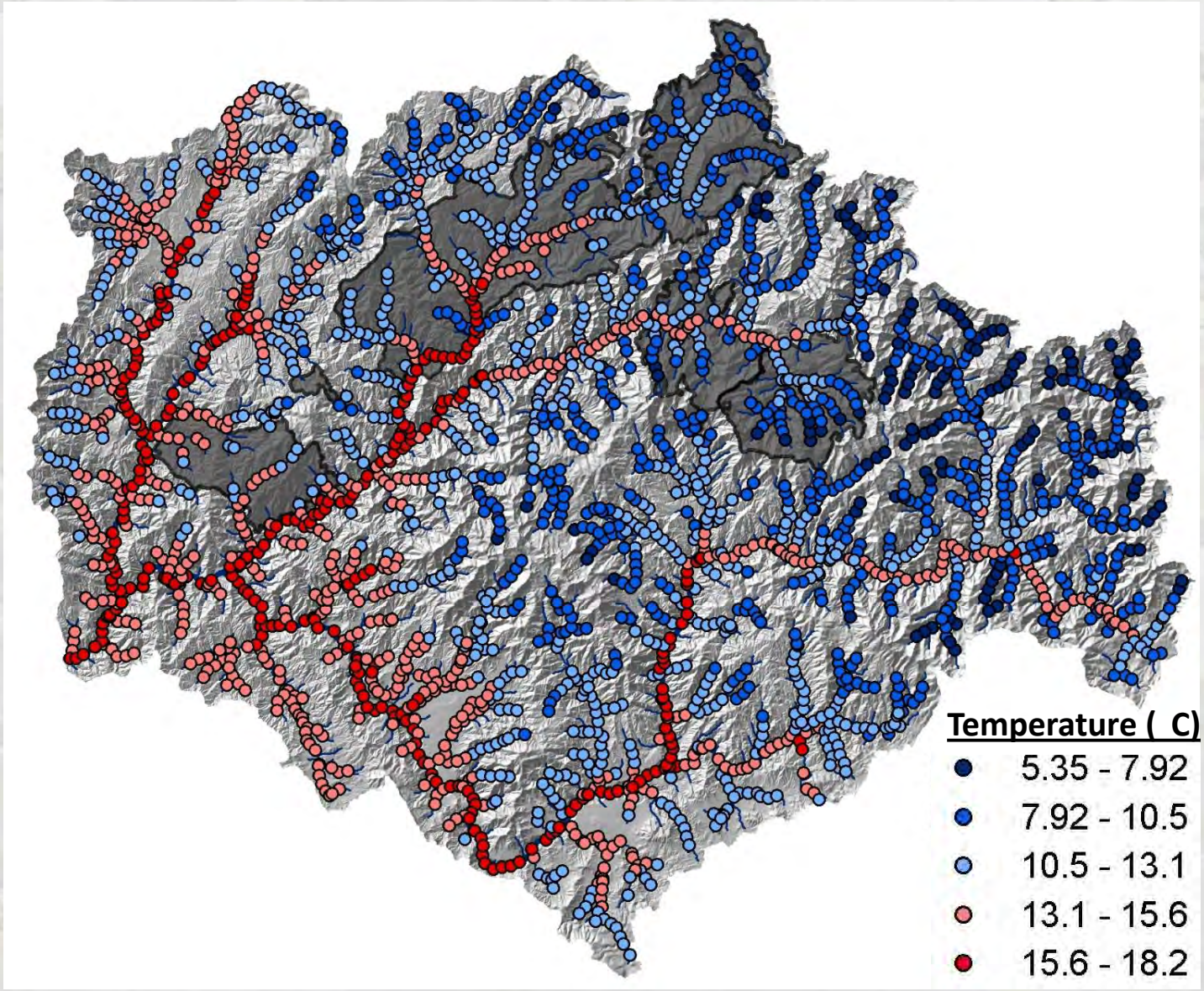


Predicted (C°) Predicted (C)

Observed (C)

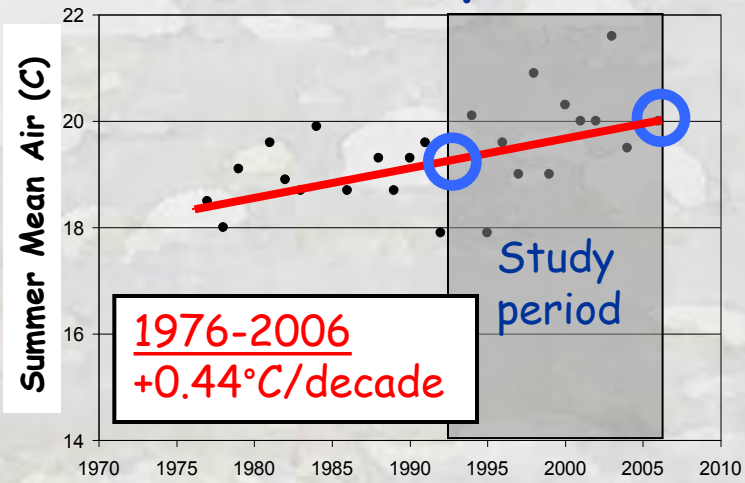
Application: River Temperature Status Map

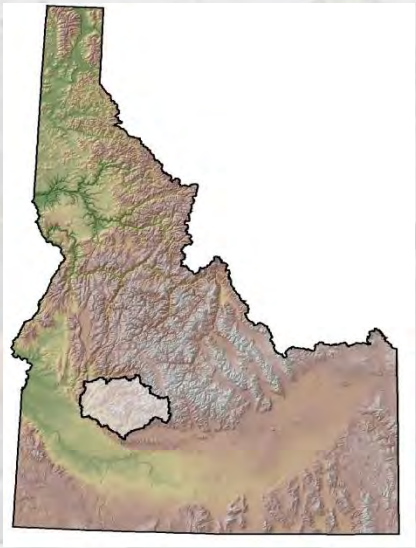
2006 Mean Summer Temperatures



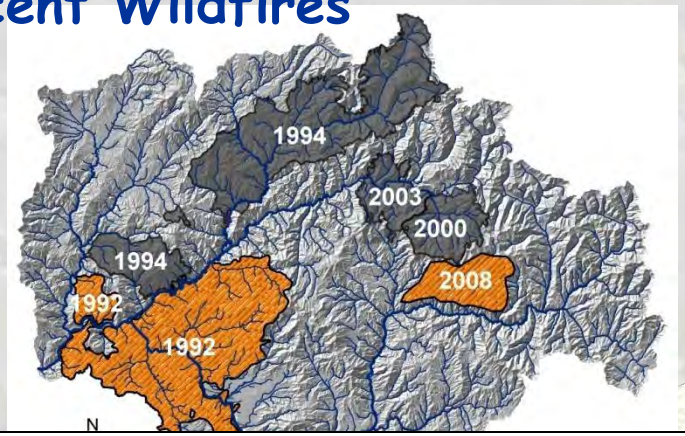
Change in Status Between Time 1 & Time 2 = Trend Assessment

Summer Air Temperature



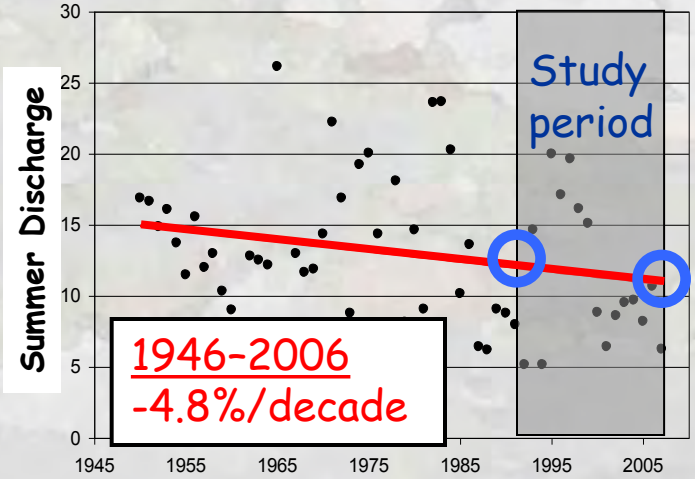


Recent Wildfires



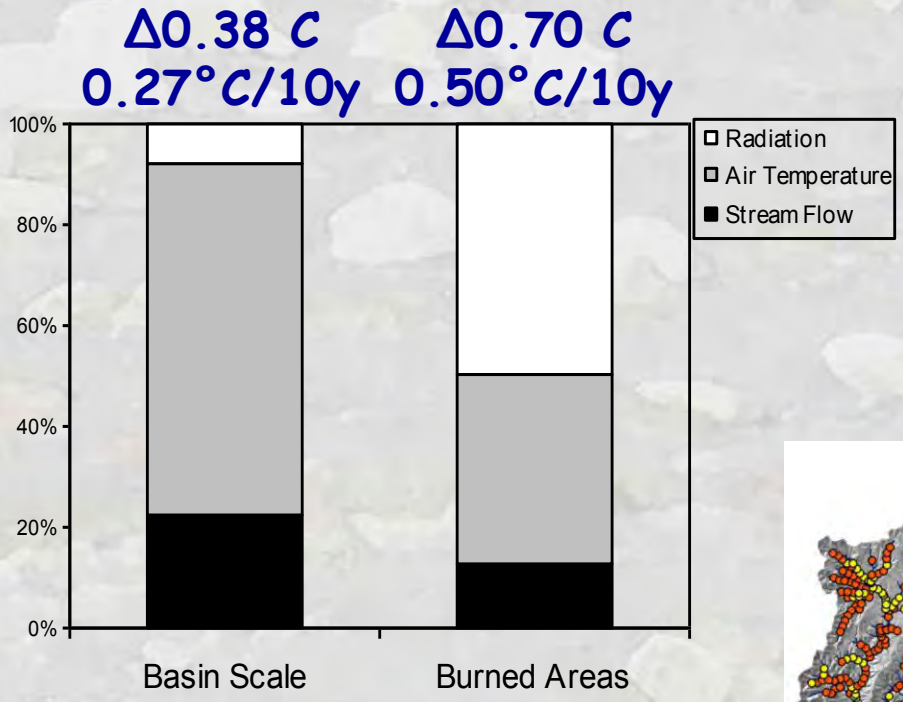
14% burned during 93-06 study period
30% burned from 92-08

Summer Stream Flow

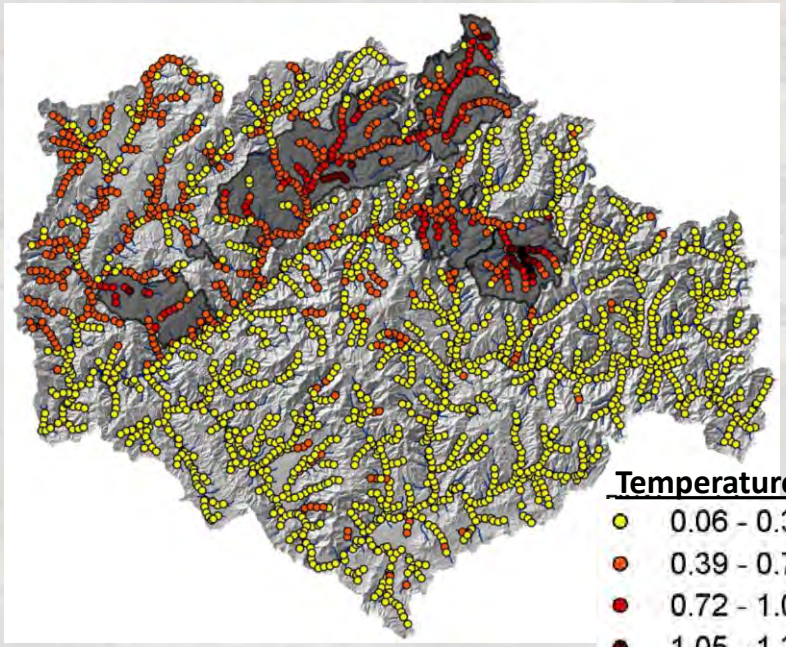


Application: Climate Change Assessment

Changes in Summer Temps (1993-2006)



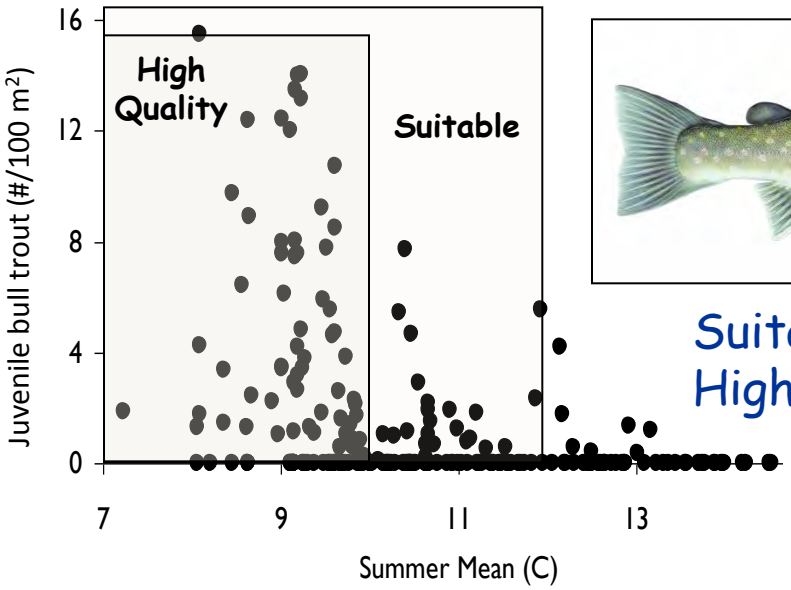
Thermal Gain Map

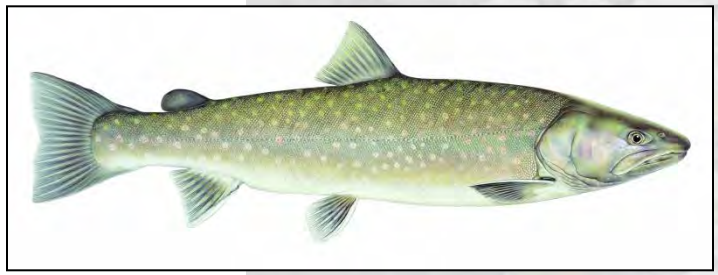


Isaak et al. 2010. *Eco. Apps.* 20:1350-1371

Application: Effects on Thermal Habitats

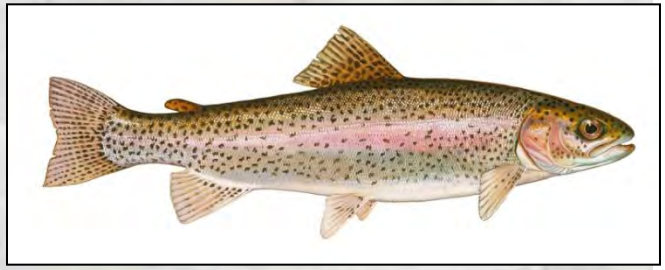
Bull Trout

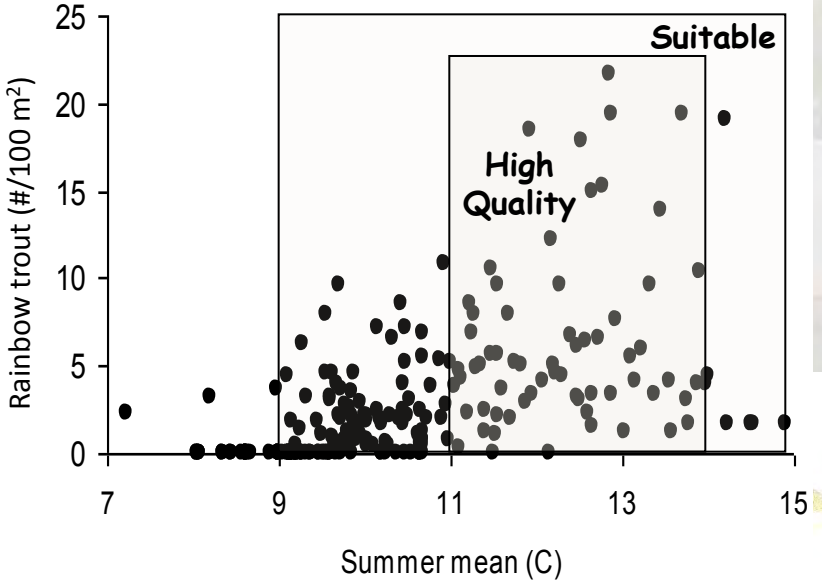




Suitable habitat < 12.0°C
High-quality habitat < 10.0°C

Rainbow Trout

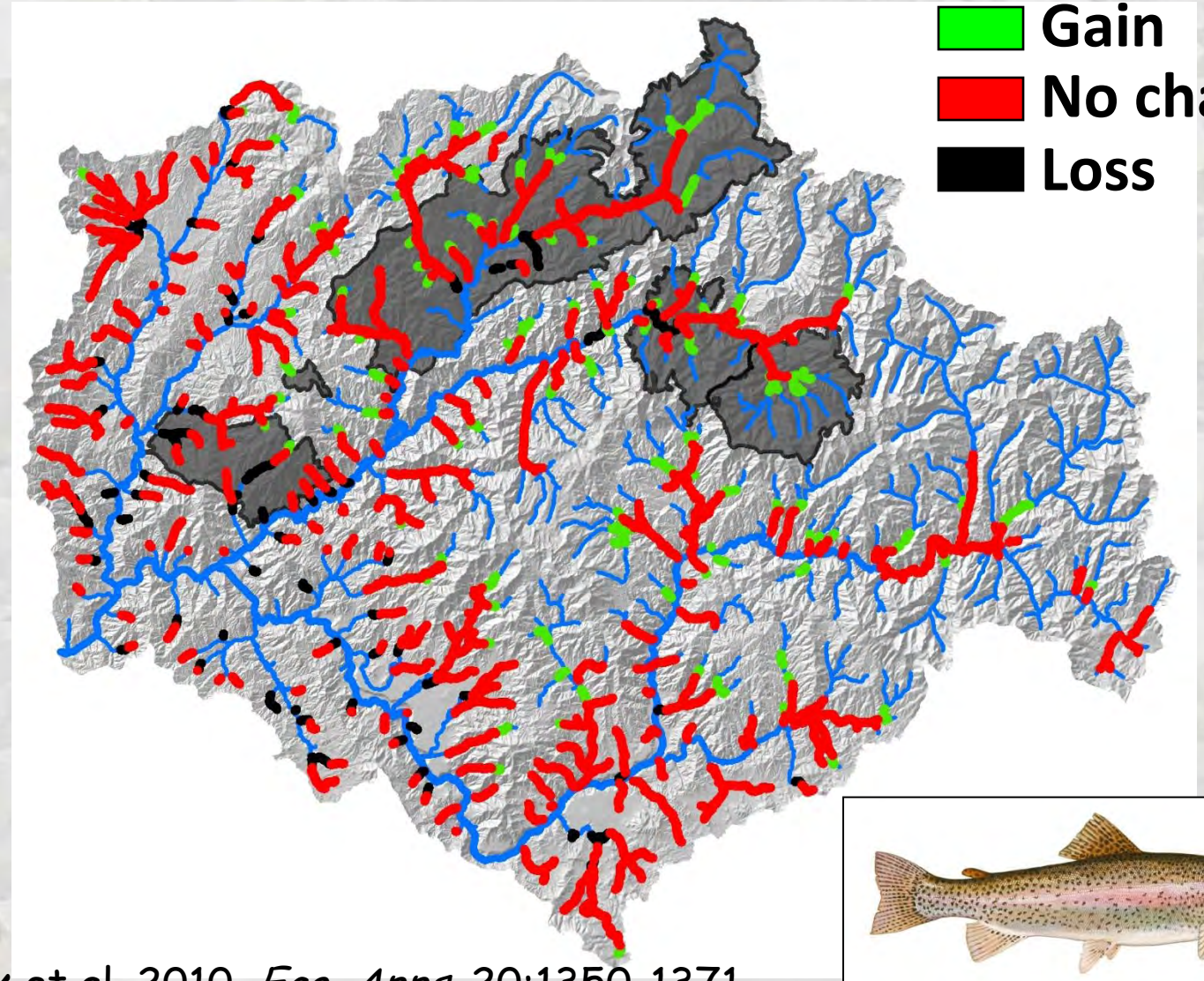




Suitable habitat = > 9.0°C
High-quality habitat = 11.0-14.0°C

93'-06' Rainbow Trout Habitat Changes

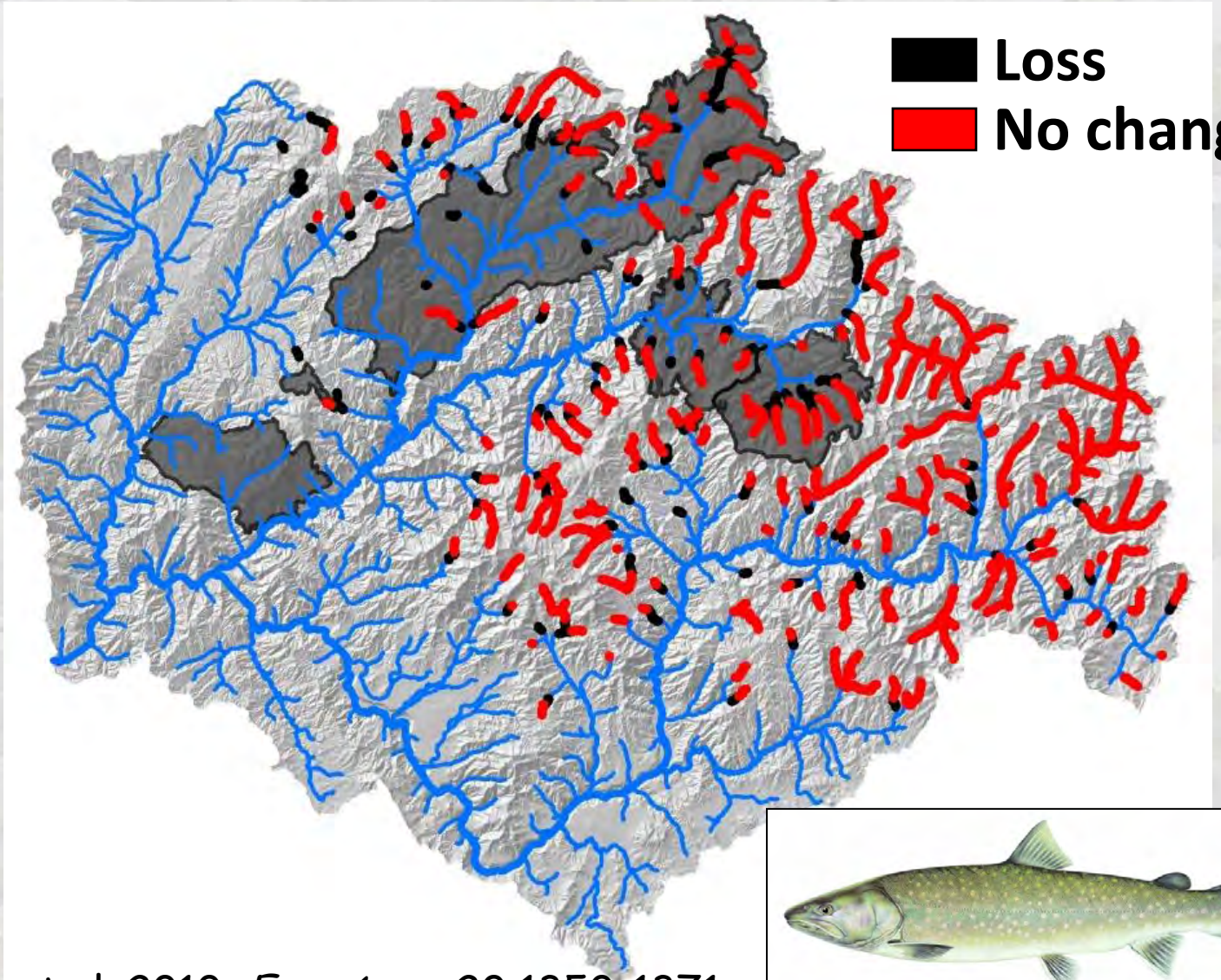
Habitat is shifting, but no net gain or loss



Isaak et al. 2010. *Eco. Apps.* 20:1350-1371

93'-06' Bull Trout Habitat Changes

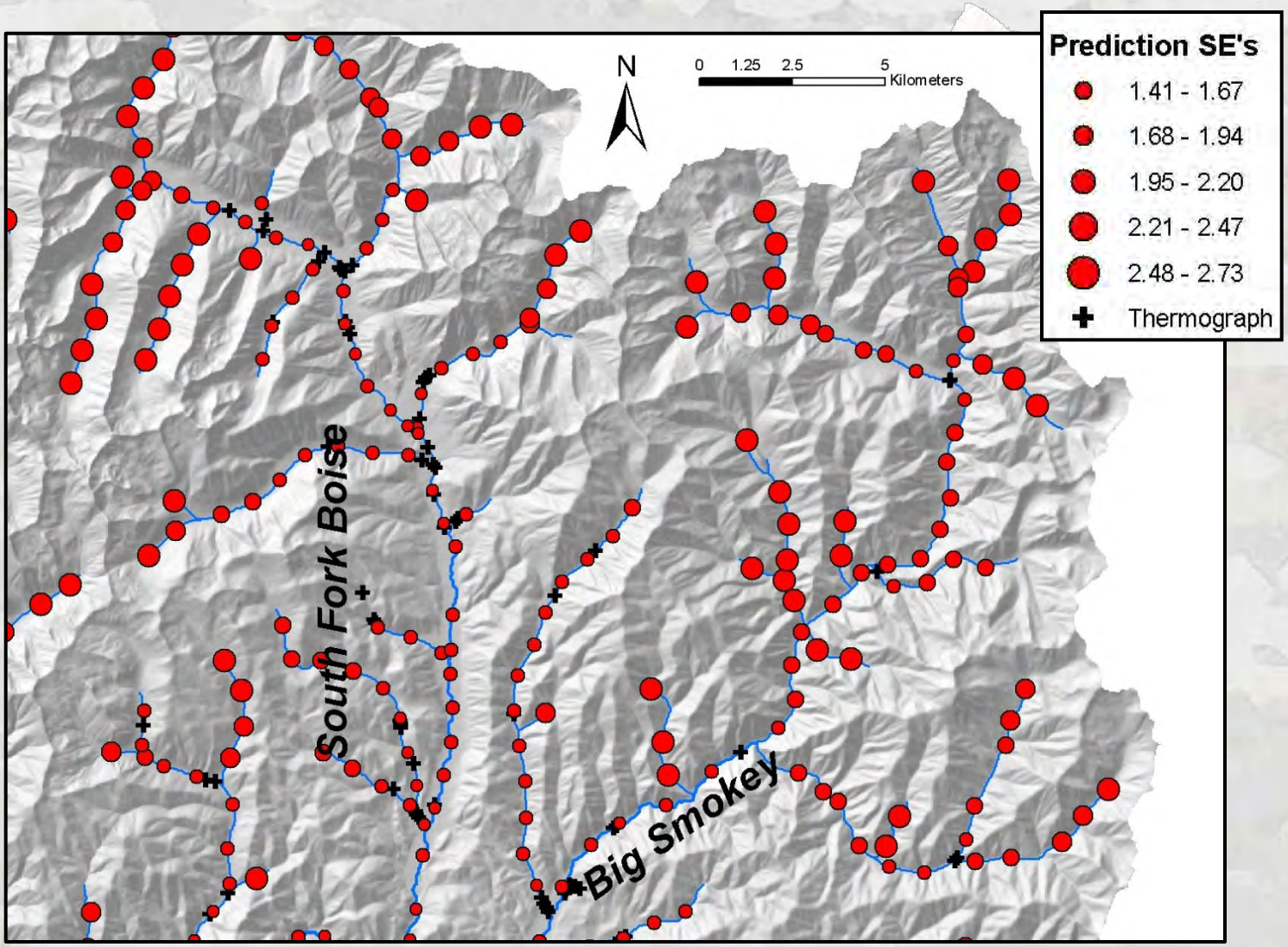
Habitat is decreasing 8%-16% / decade



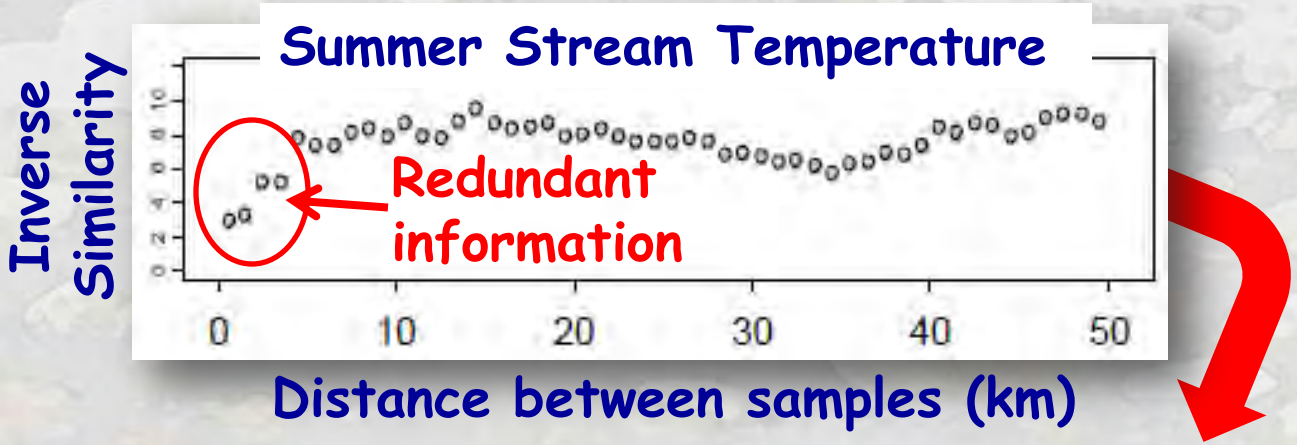
Isaak et al. 2010. *Eco. Apps.* 20:1350-1371

Mapping Uncertainty

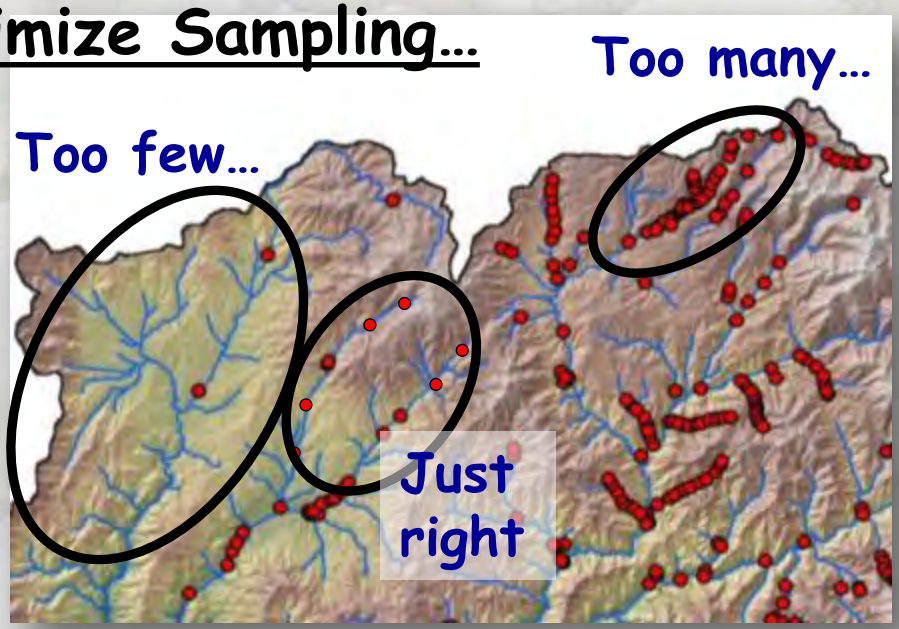
Temperature Prediction Precision



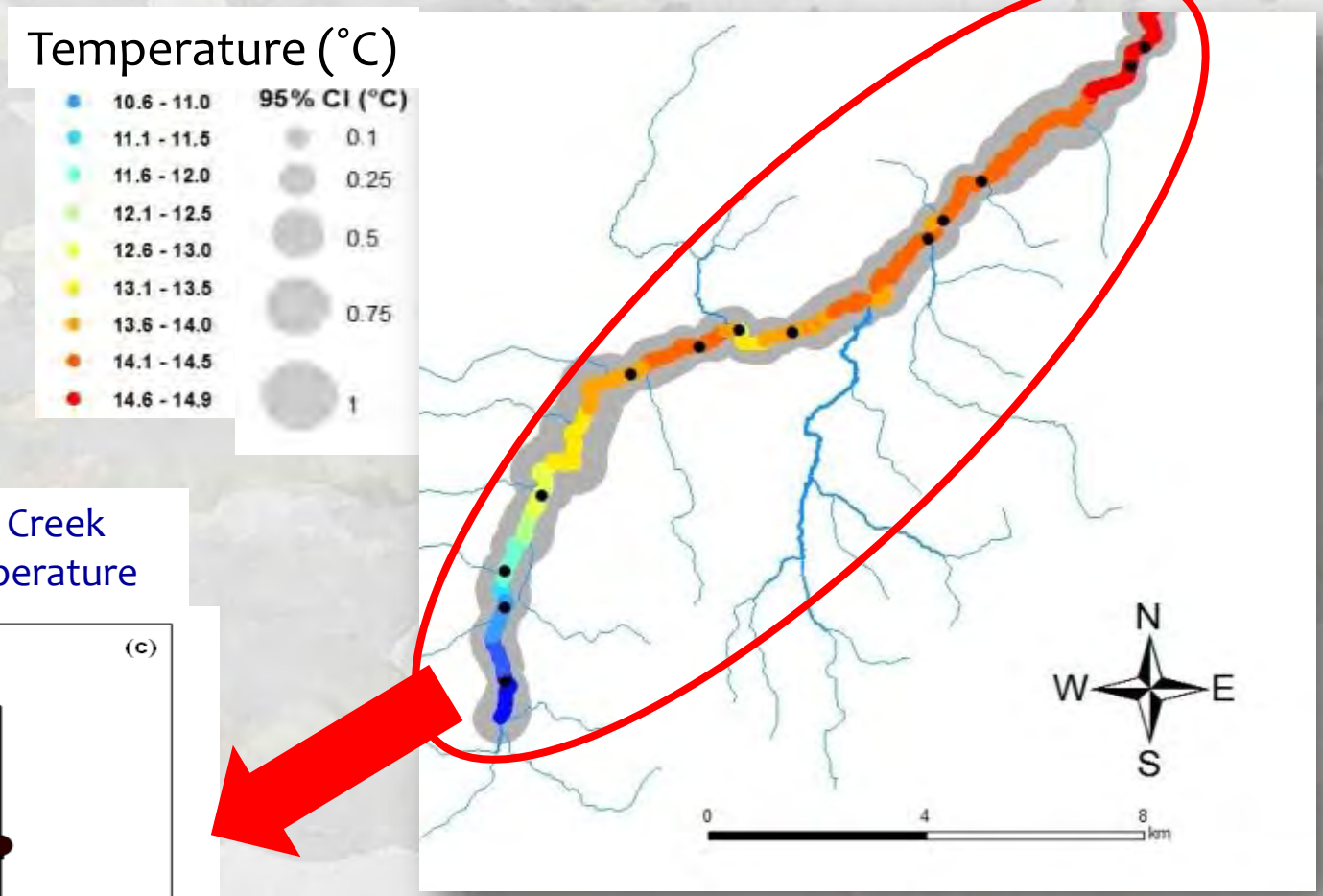
Application: Efficient Monitoring Designs



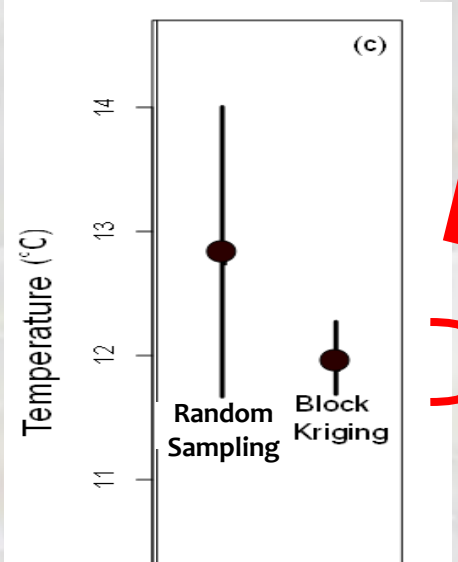
Optimize Sampling…



Application: Block-Kriging for Accurate Estimates at User-Defined Scales



Bear Valley Creek
Mean Temperature

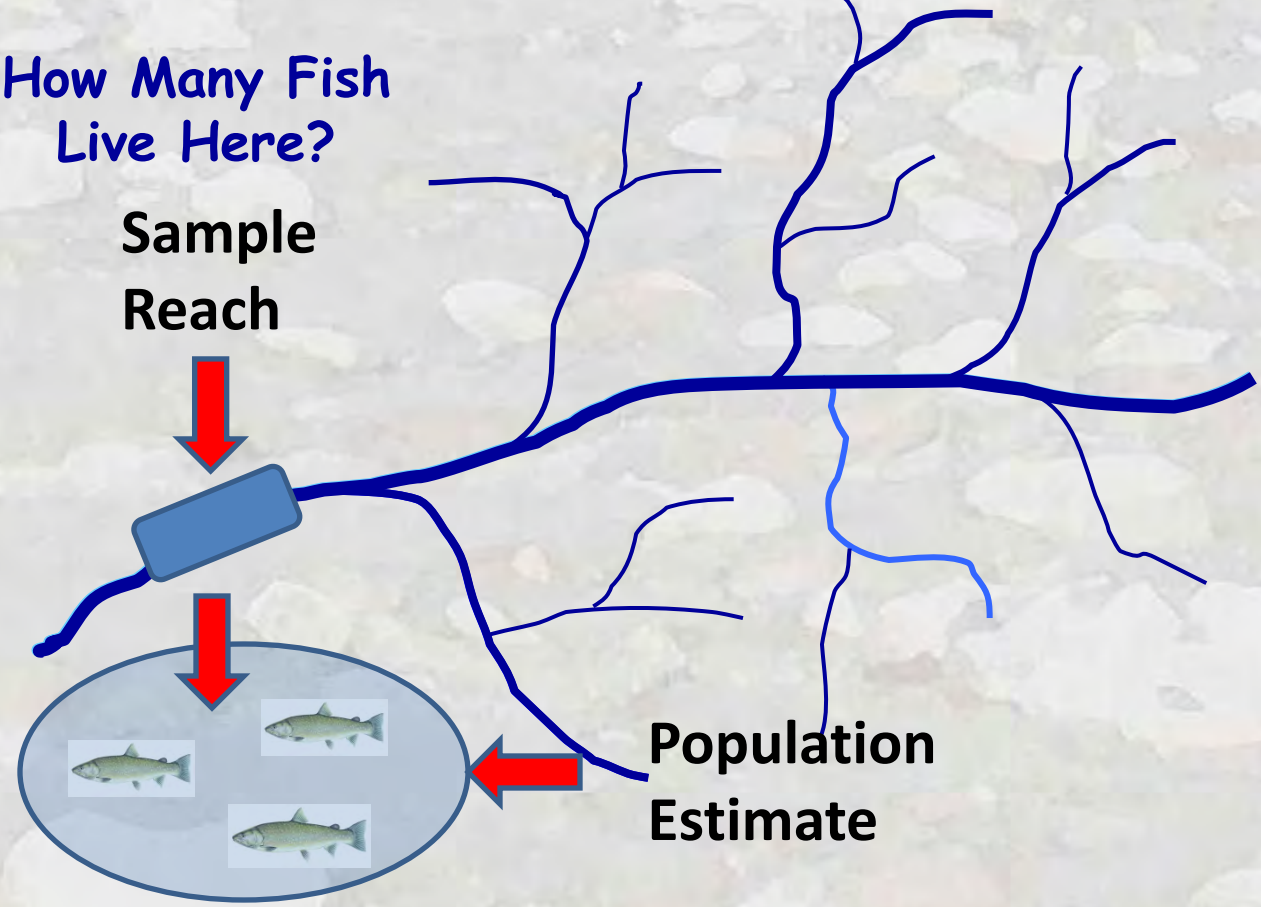


Spatial estimates are often less biased and more precise

Application: Block-Kriging for Accurate Estimates at User-Defined Scales

Population Estimates for Aquatic Organisms

How Many Fish Live Here?

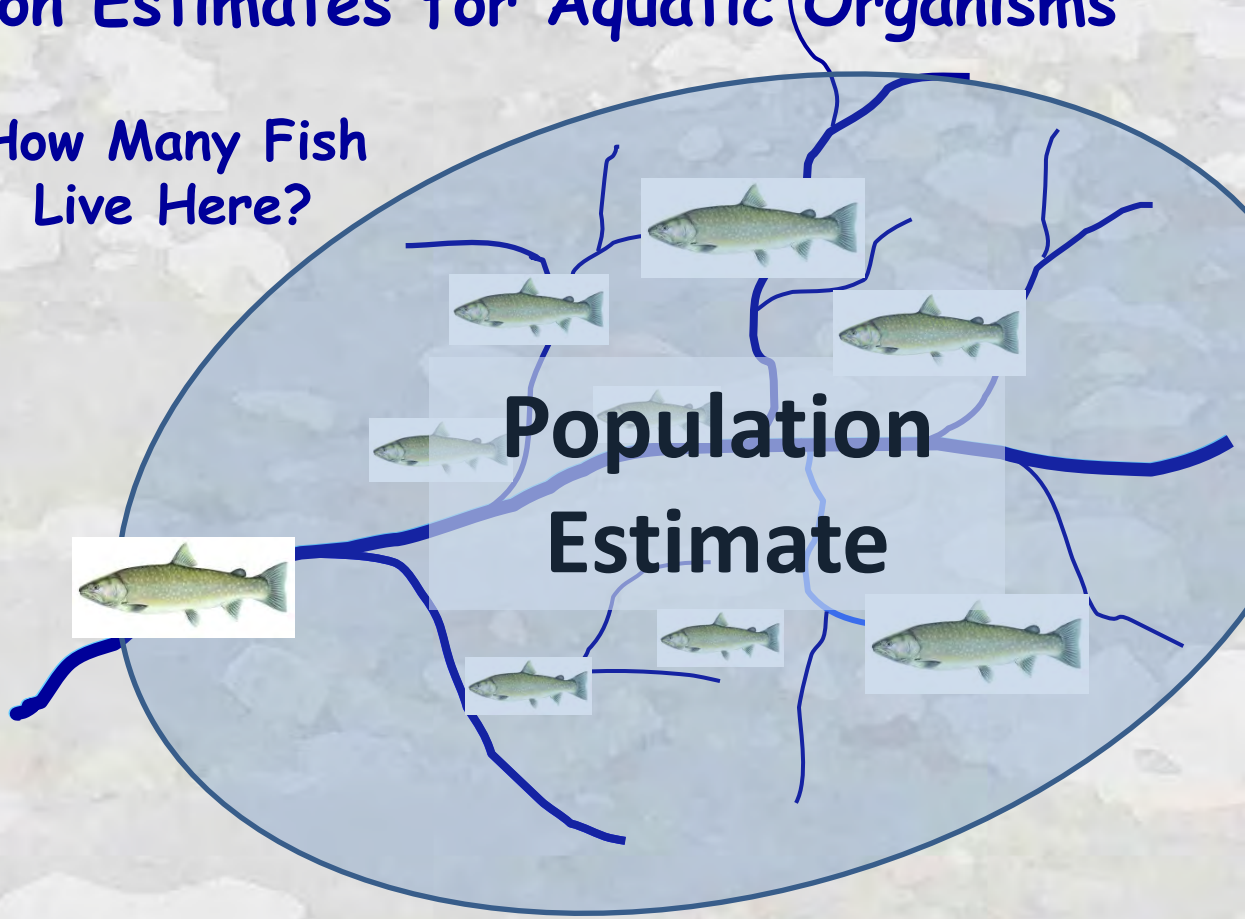


Traditional Estimation Scale = Reach (10's – 100's meters)

Block-Kriging for Stream & Basin-scale Population Estimates (Poisson link function)

Population Estimates for Aquatic Organisms

How Many Fish Live Here?



Desired Estimation Scale =
Stream & Network (1000's – 10,000's meters)

Block-Kriging for Stream & Basin-scale Population Estimates (Poisson link function)

Population Estimates for Aquatic Organisms

Environ Ecol Stat (2008) 15:3–13
DOI 10.1007/s10651-007-0035-y

Spatial methods for plot-based sampling of wildlife populations

Jay M. Ver Hoef

- Terrestrial applications are common
- Theory now exists for streams

ECOSCIENCE 9 (2) : 152-161 (2002)

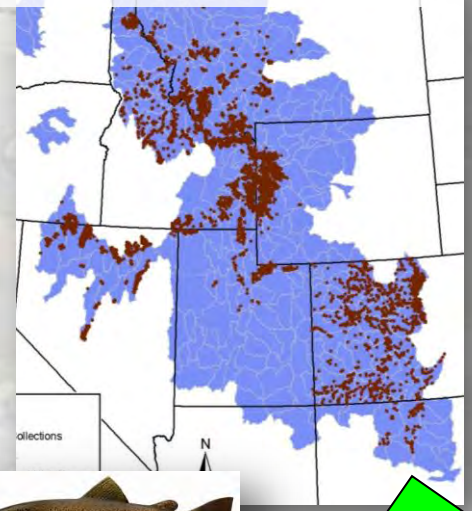
Sampling and geostatistics for spatial data[1]

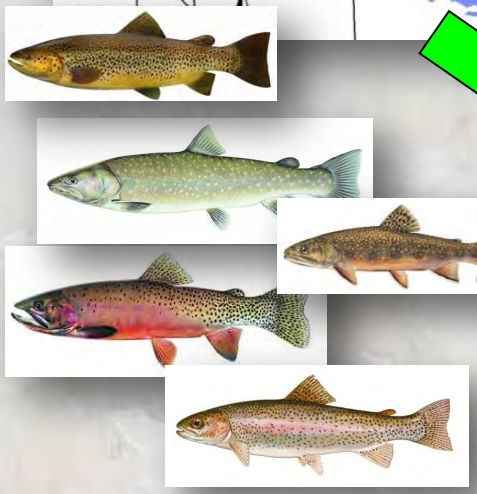
Jay VER HOEF, Alaska Department of Fish and Game, 1300 College Road, Fairbanks, Alaska 99701, U.S.A.,
e-mail: jay_ver_hoef@fishgame.state.ak.us

Desired Estimation Scale =
Stream & Network (1000's – 10,000's meters)

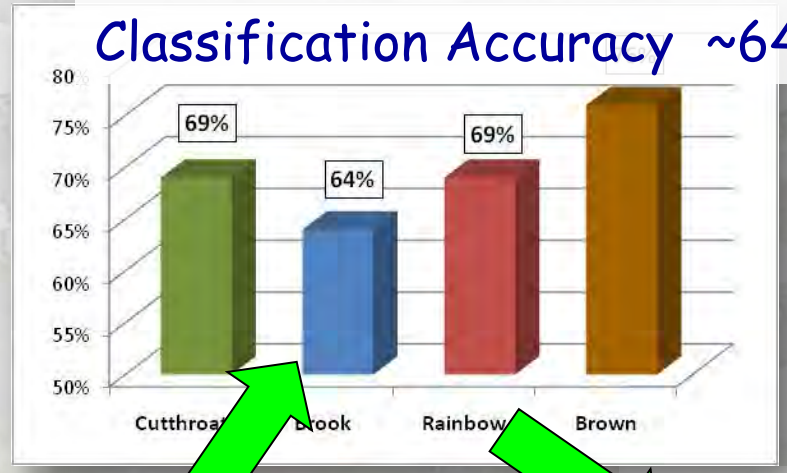
Application: Improved Species Distribution Models (binary link function)

Fish survey database ~10,000

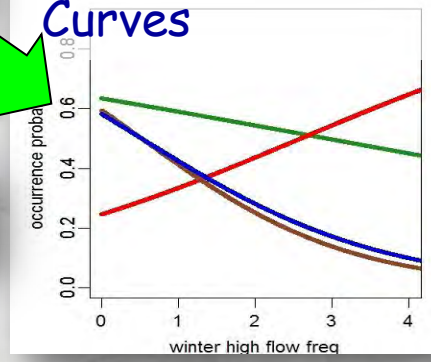




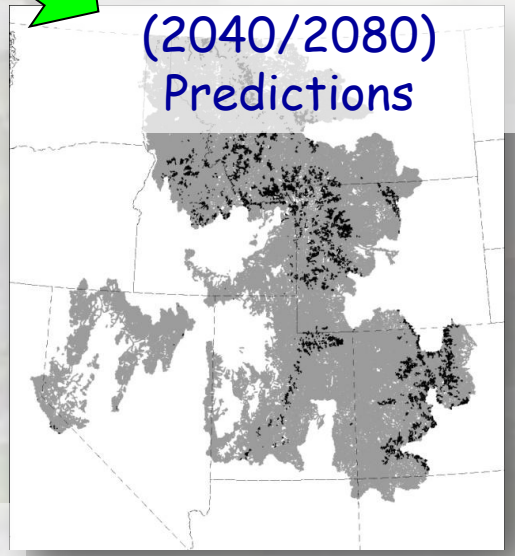
Classification Accuracy ~64% – 75%



Species-Specific Habitat Response Curves



Current & Future (2040/2080) Predictions

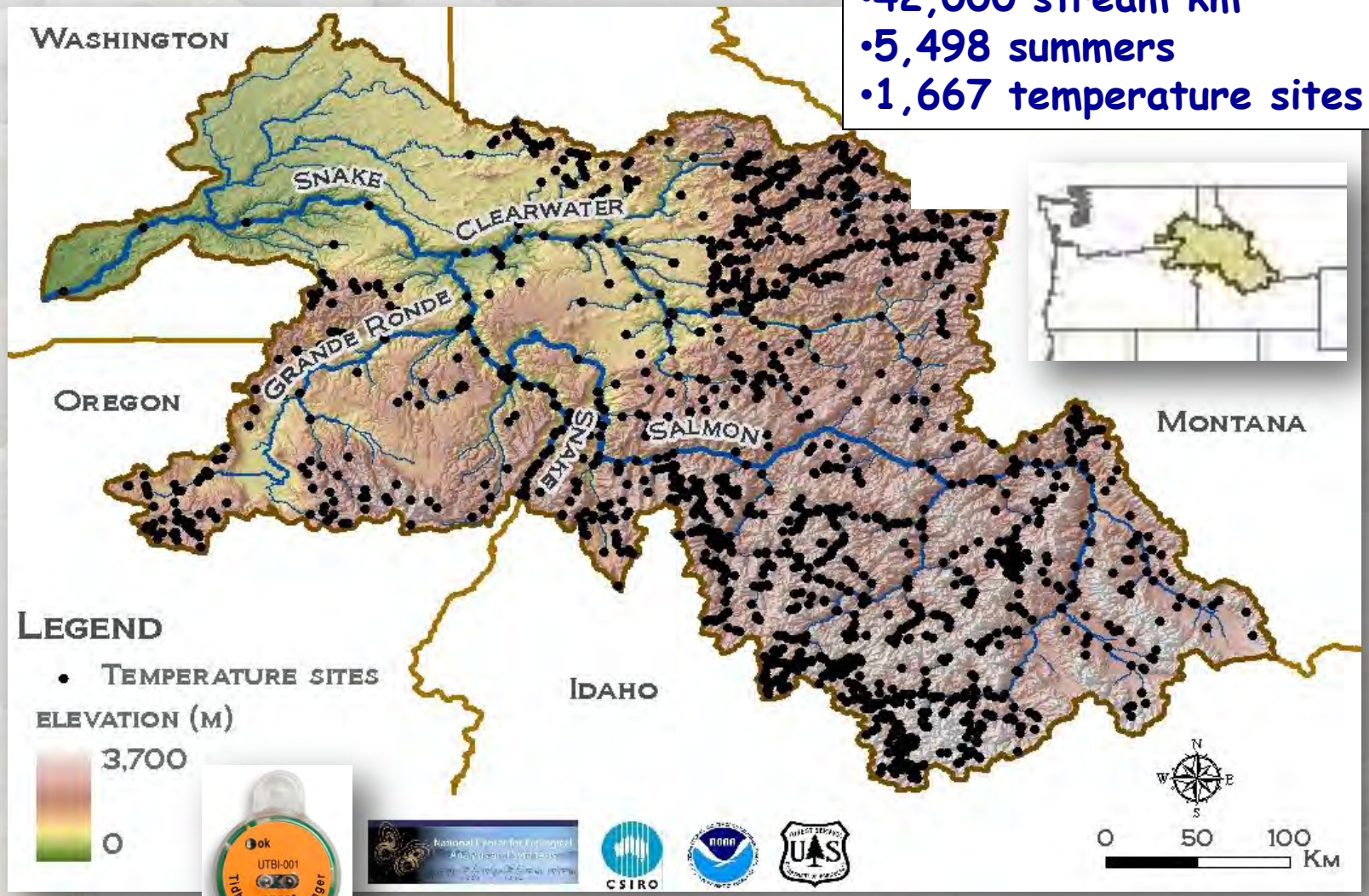


Wenger et al., in preparation

Computation Challenges: BIG DATA

NCEAS - Lower Snake Hydrologic Region

- 42,000 stream km
- 5,498 summers
- 1,667 temperature sites



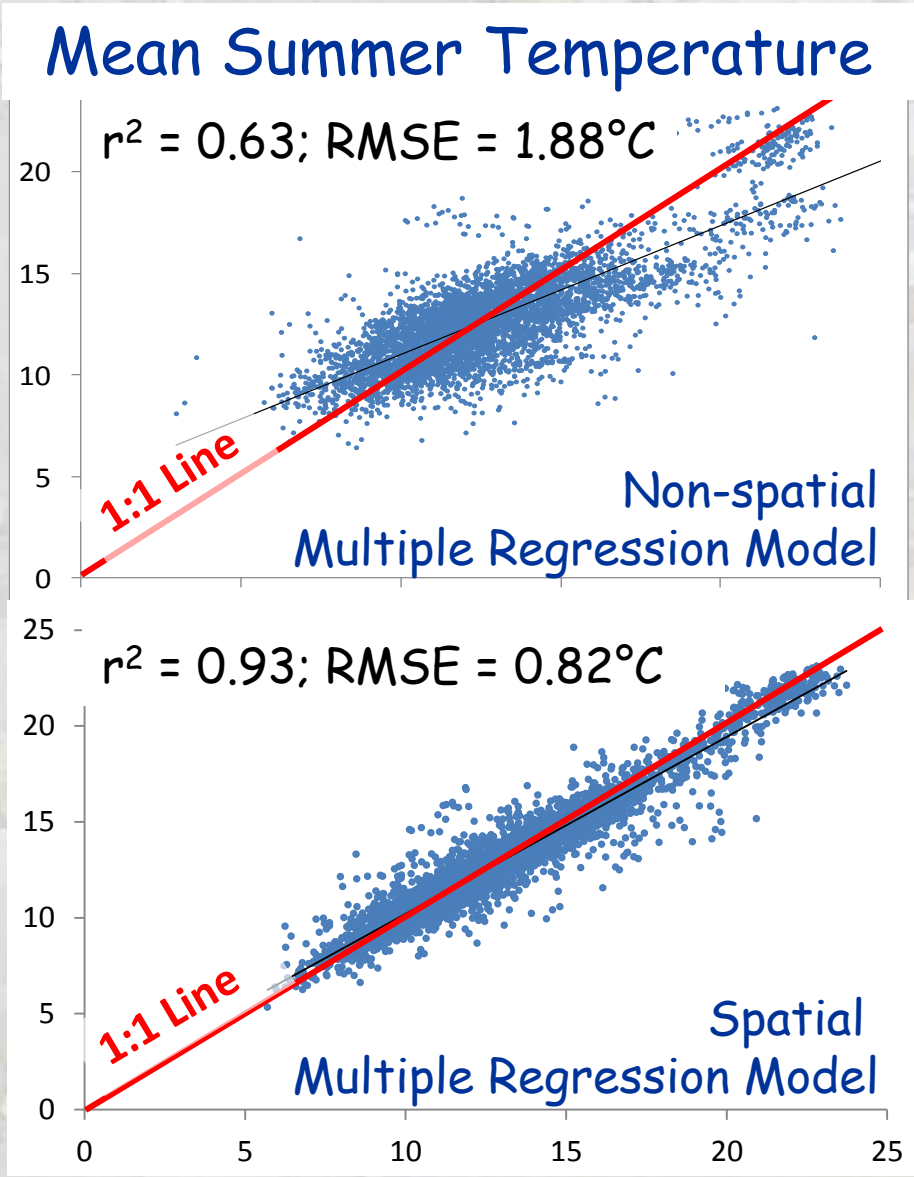
Peterson, Ver Hoef, and Isaak 2010

Lower Snake VHP Temperature Model

n = 5,498

Non-spatial Stream Temp =
- 0.0041*Ele (m)
- 13.9*Slope (%)
+ 0.016*Wat_size (100km²)
-0.0022*Ave_Precip
- 0.041*Flow (m³/s)
+ 0.42*AirMean (C)

Spatial Stream Temp =
- 0.0045*Ele (m)
- 9.8*Slope (%)
+ 0.012*Wat_size (100km²)
- 0.00061*Ave_Precip
- 0.037*Flow (m³/s)
+ 0.46*AirMean (C)



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

Dan Isaak, Seth Wenger[1], Erin Peterson[2], Jay Ver Hoef[3] Charlie Luce, Steve Hostetler[4], Jason Dunham[4], Jeff Kershner[4], Brett Roper, Dave Nagel, Dona Horan, Gwynne Chandler, Sharon Parkes, Sherry Wollrab

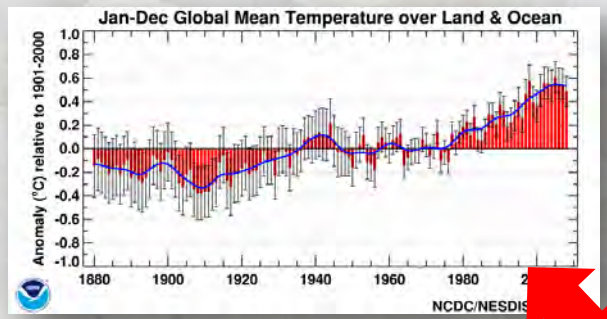
U.S. Forest Service

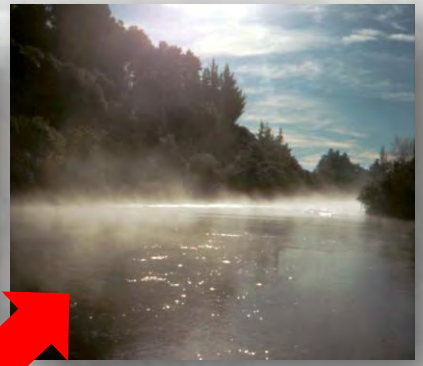
[1]Trout Unlimited

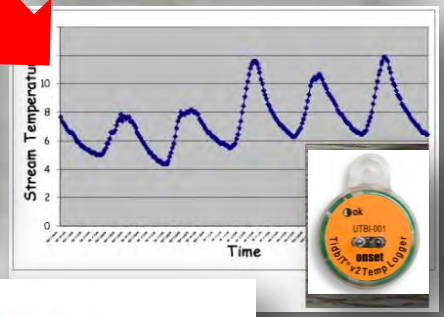
[2]CSIRO

[3]NOAA

[4]USGS

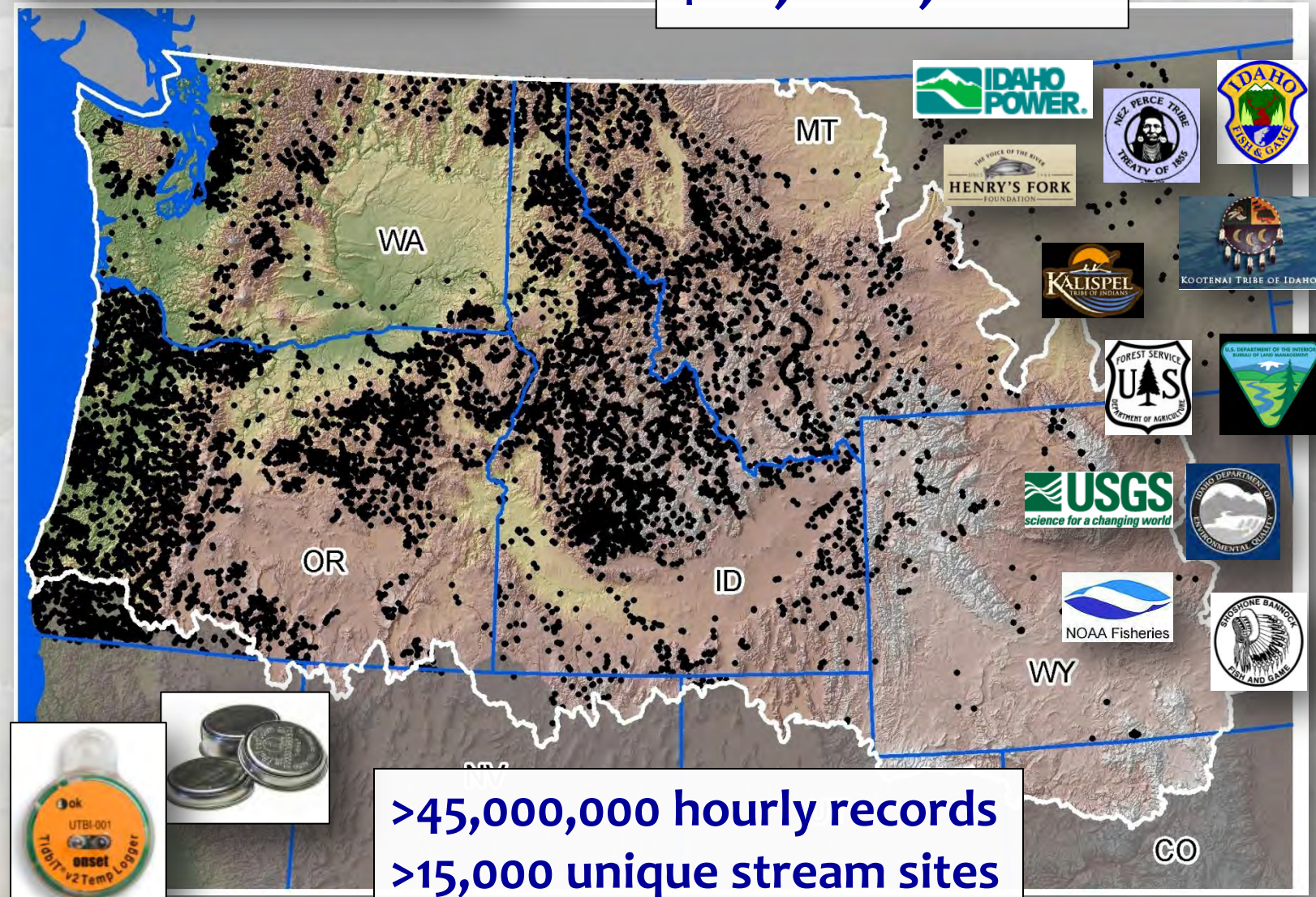






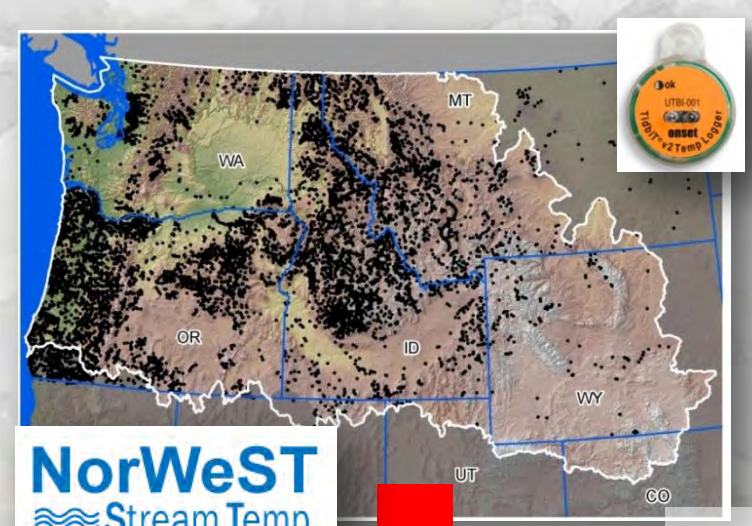
NorWeST Stream Temp

>60 agencies
$10,000,000



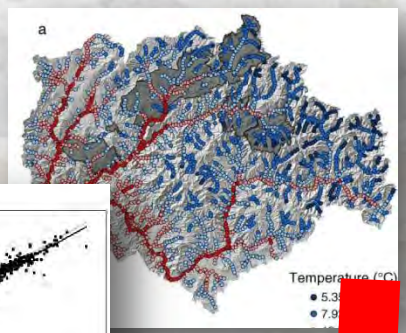
>45,000,000 hourly records
>15,000 unique stream sites

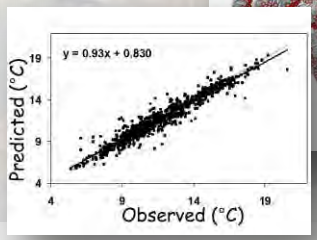
Regional Temperature Model



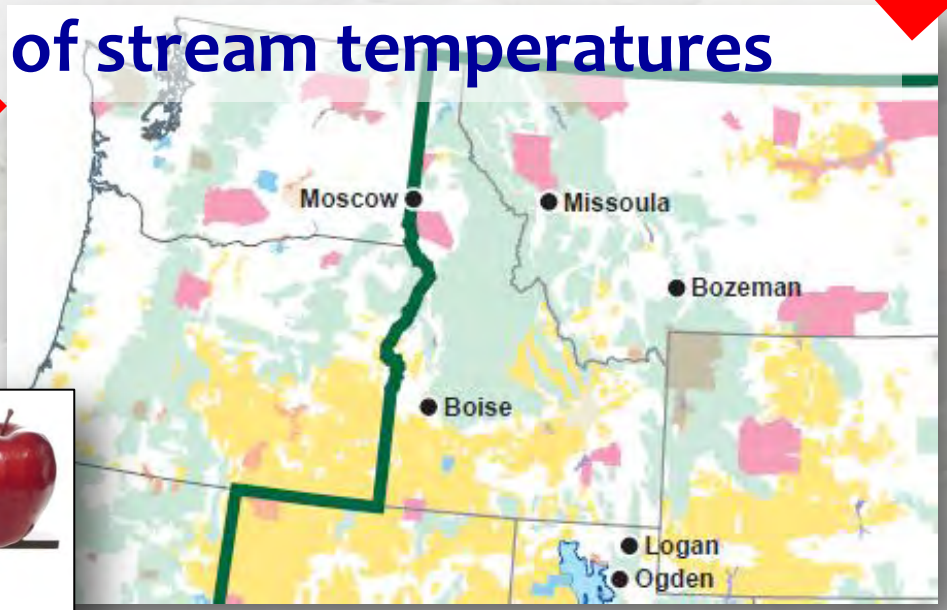
NorWeST
Stream Temp

Accurate temperature models

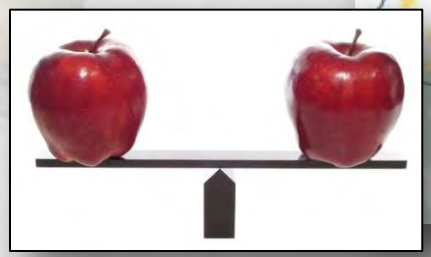




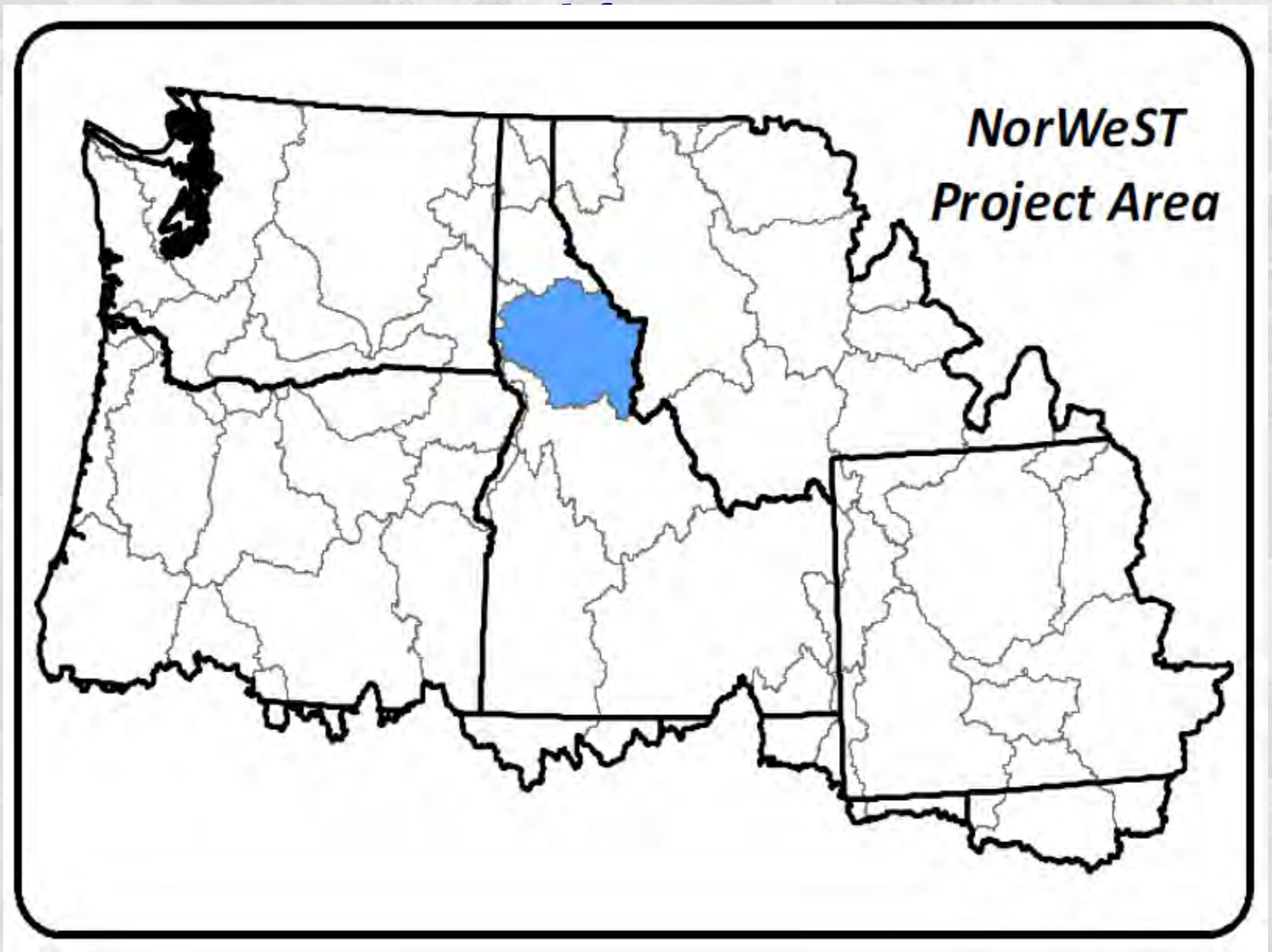
Cross-jurisdictional "maps" of stream temperatures



Consistent datum for strategic assessments across 350,000 stream kilometers



Example: Clearwater River Basin

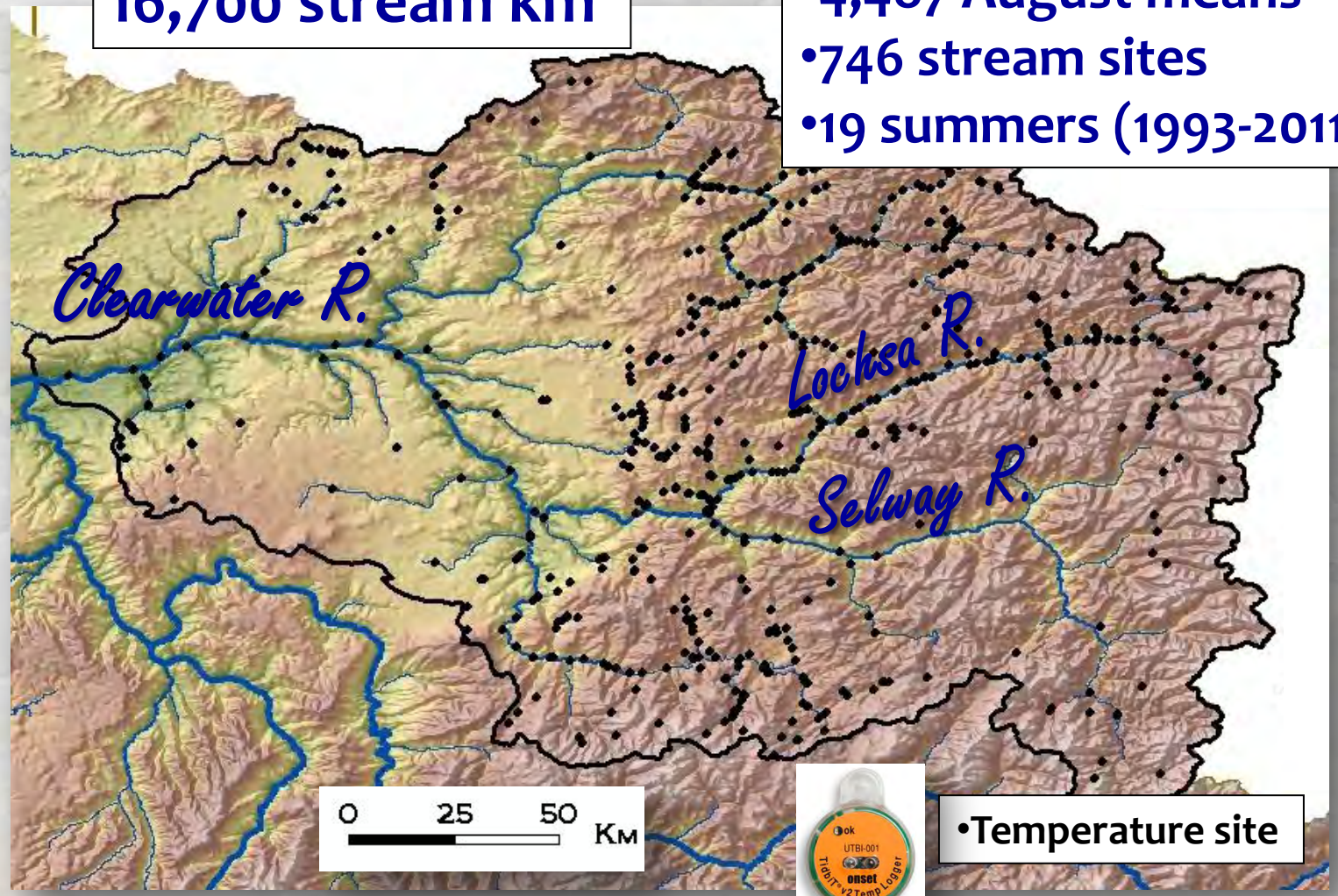


Example: Clearwater River Basin

Data extracted from NorWeST

16,700 stream km

- 4,487 August means
- 746 stream sites
- 19 summers (1993-2011)



Clearwater River Temp Model

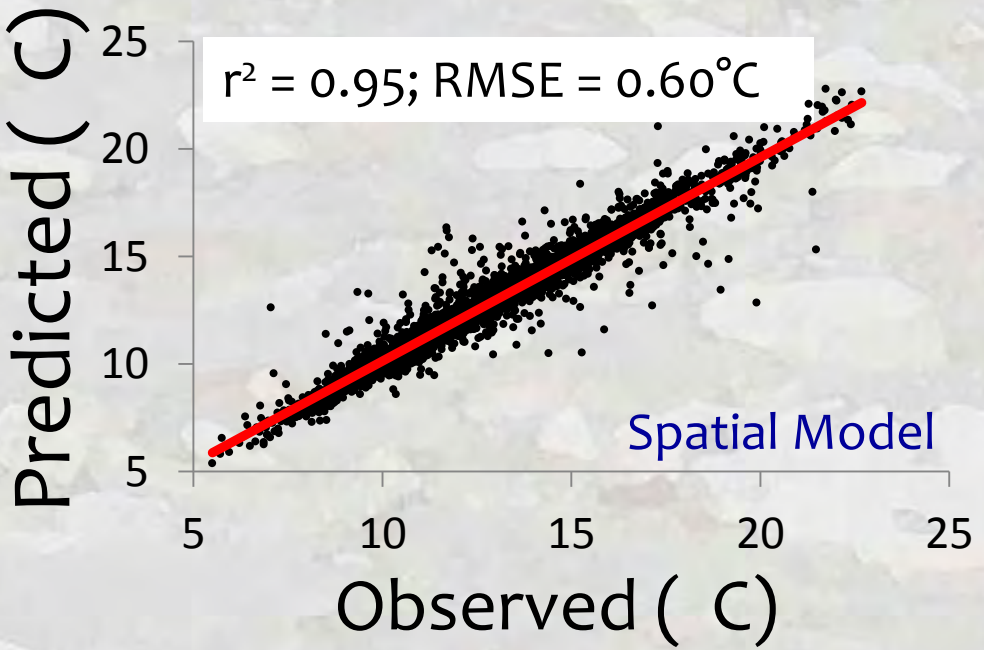
n = 4,487

Covariate Predictors

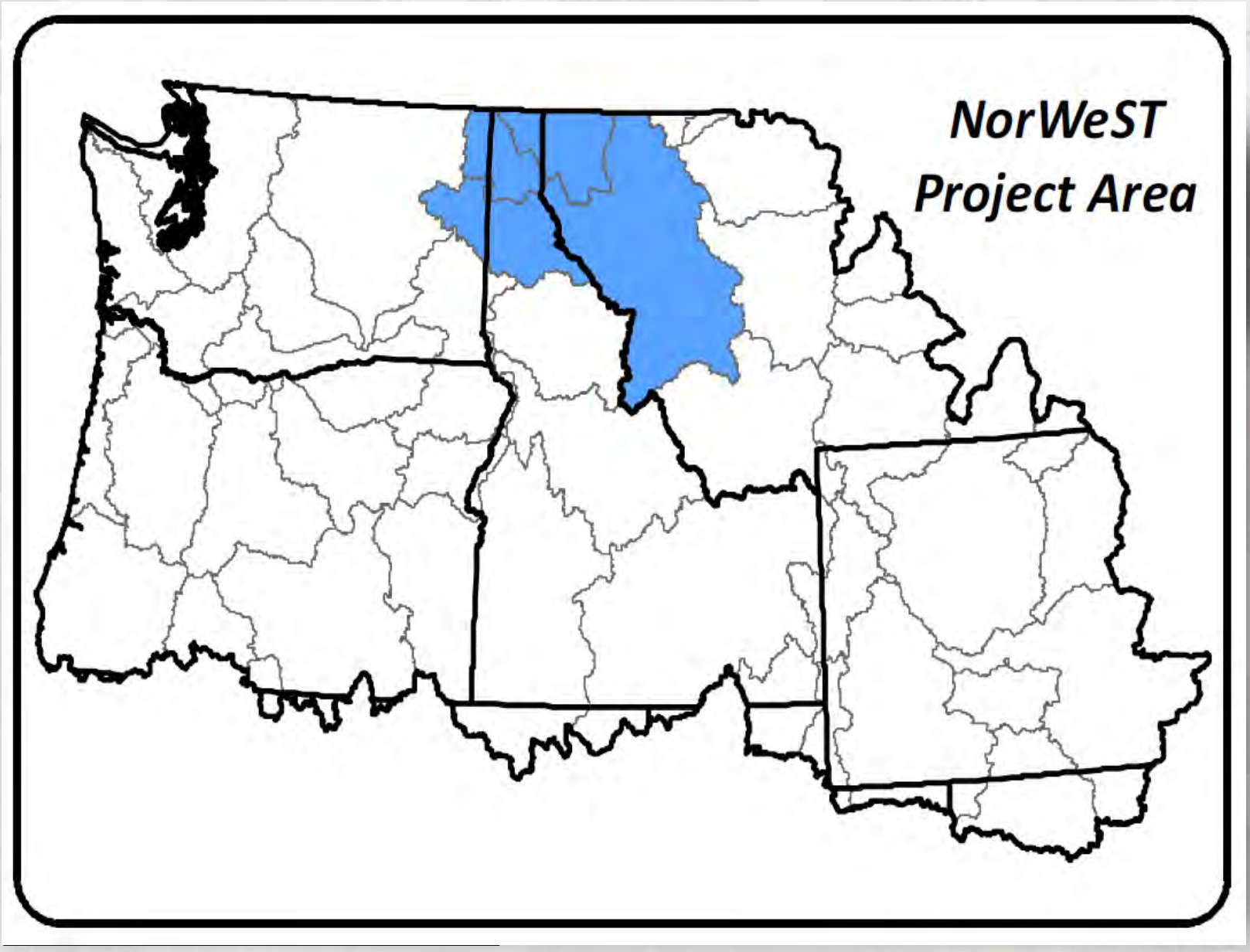
1. Elevation (m)
2. Canopy (%)
3. Stream slope (%)
4. Ave Precipitation (mm)
5. Latitude (km)
6. Lakes upstream (%)
7. Baseflow Index
8. Watershed size (km^2)

9. Discharge (m^3/s)
   USGS gage data
10. Air Temperature (˚C)
    RegCM3 NCEP reanalysis
    Hostetler et al. 2011

Mean August Temperature

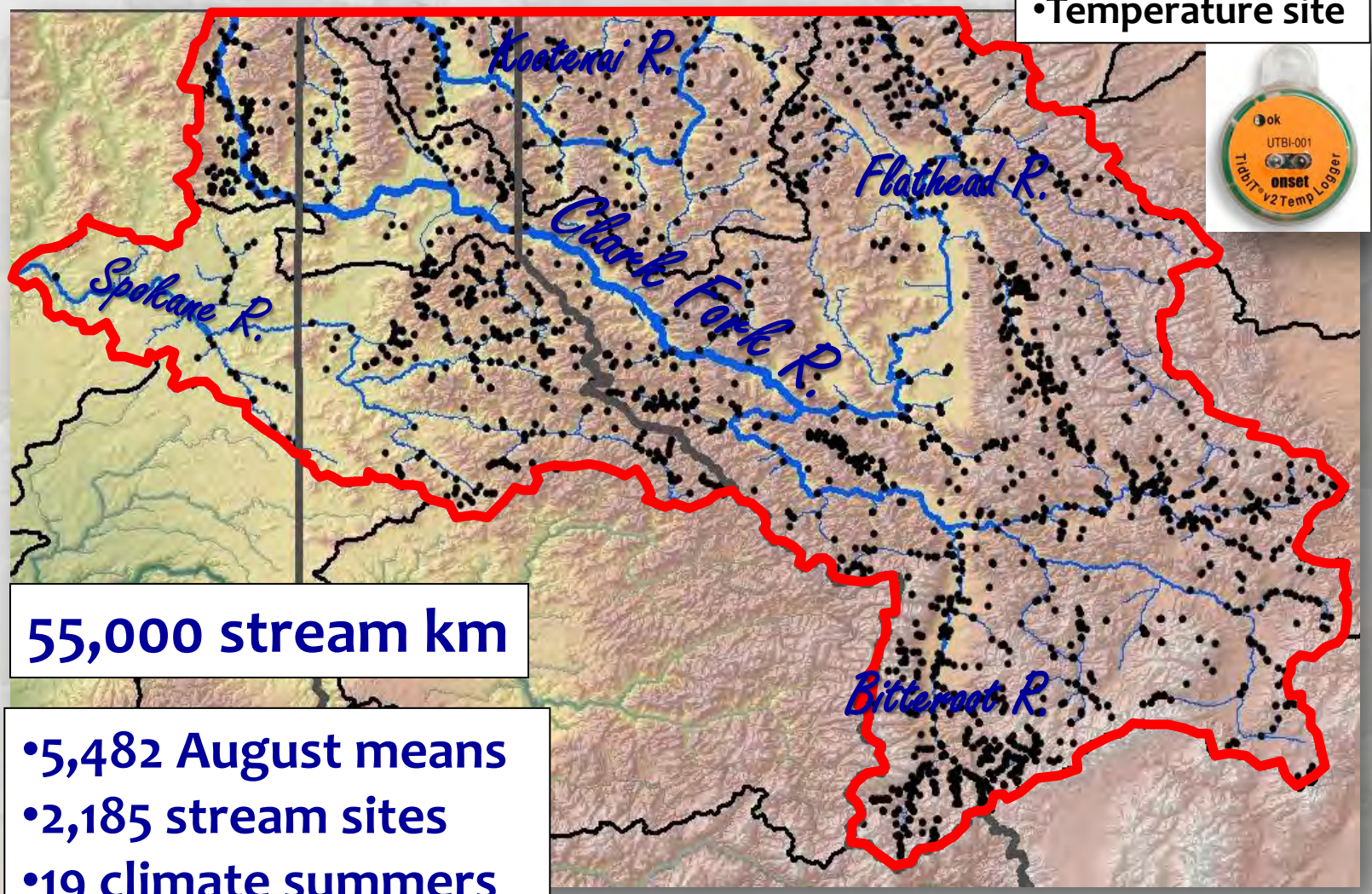


Example: SpoKoot River Basins



Example: SpoKoot River Basins

Data extracted from NorWeST



SpoKoot River Temp Model

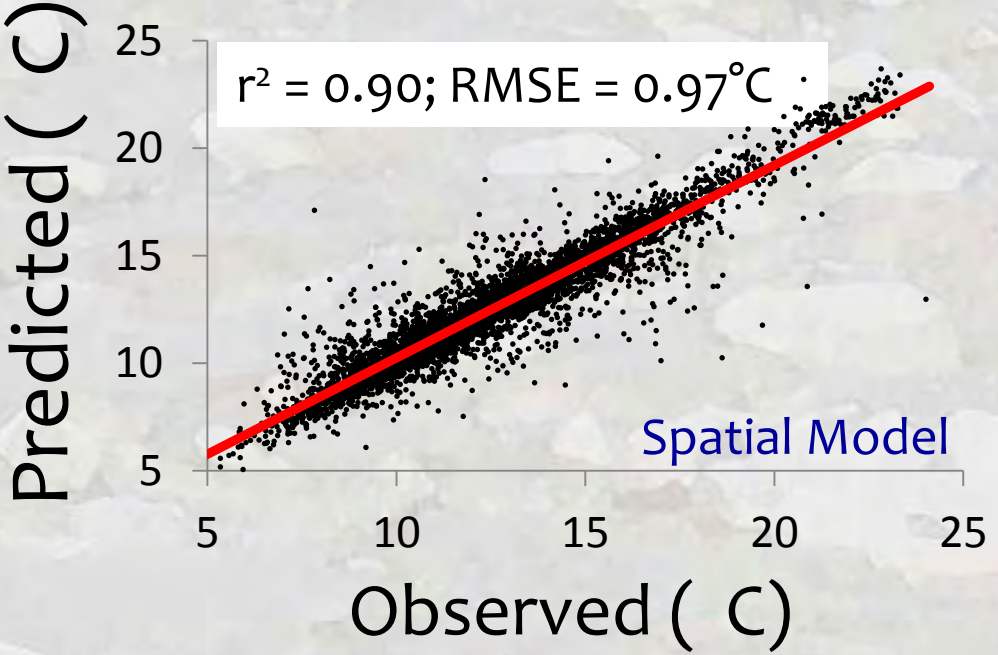
n = 5,482

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)

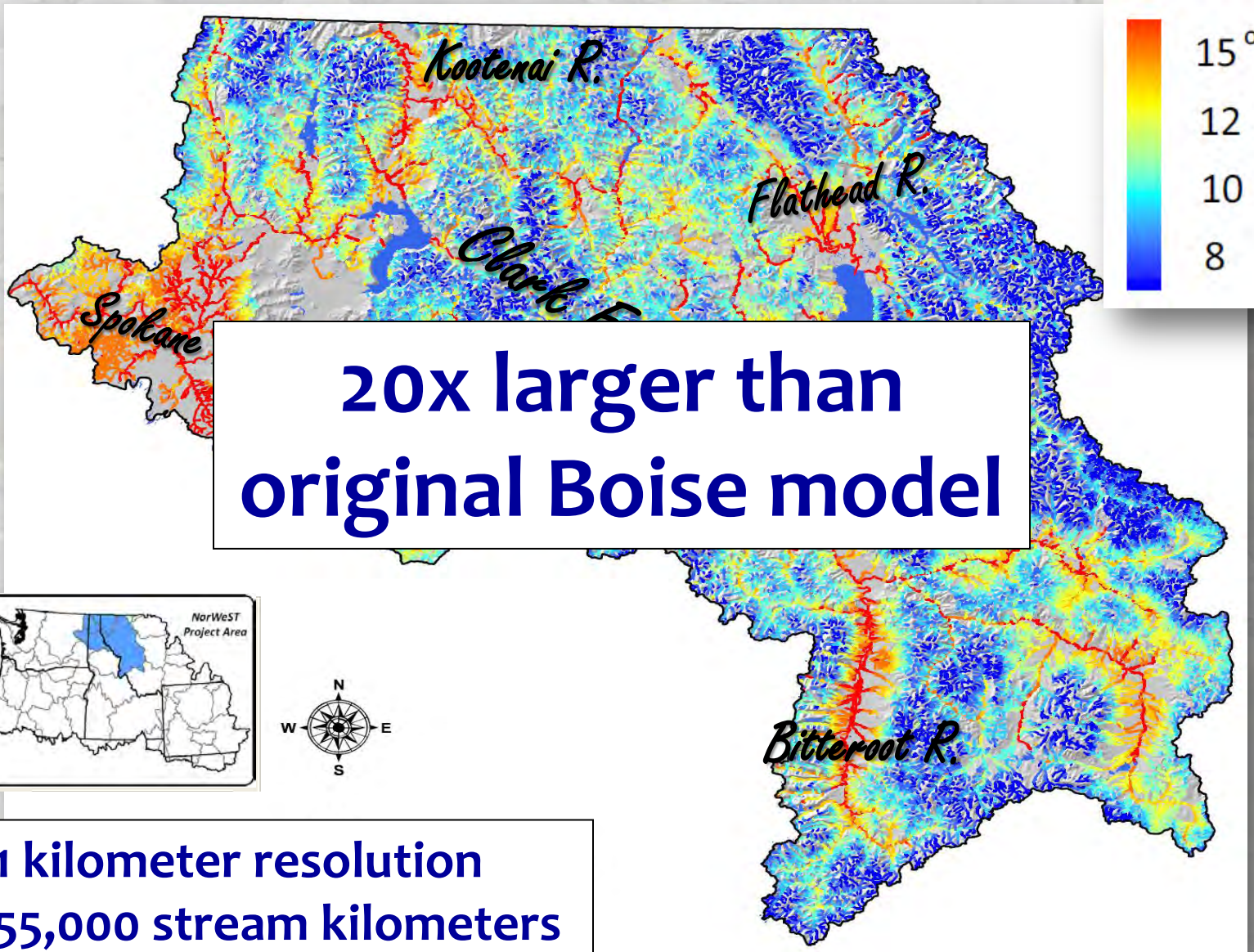
9. Discharge (m^3/s)
   USGS gage data
10. Air Temperature (˚C)
    RegCM3 NCEP reanalysis
    Hostetler et al. 2011

Mean August Temperature



Kriged Prediction Map of Climate Scenario

1993-2011 mean August stream temperatures

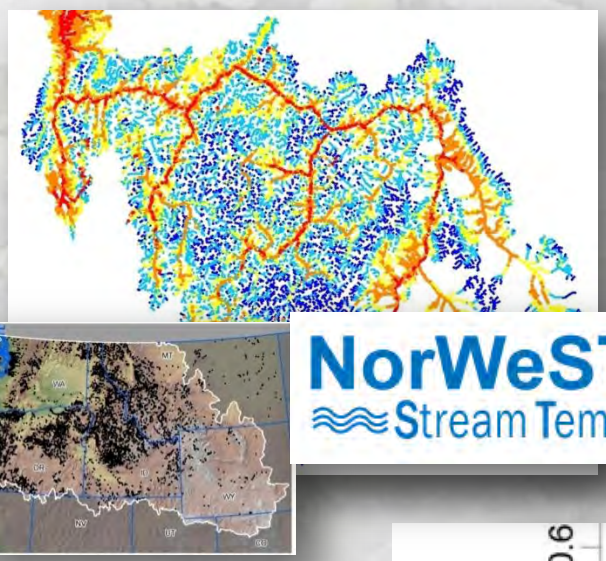


20x larger than original Boise model

1 kilometer resolution
55,000 stream kilometers

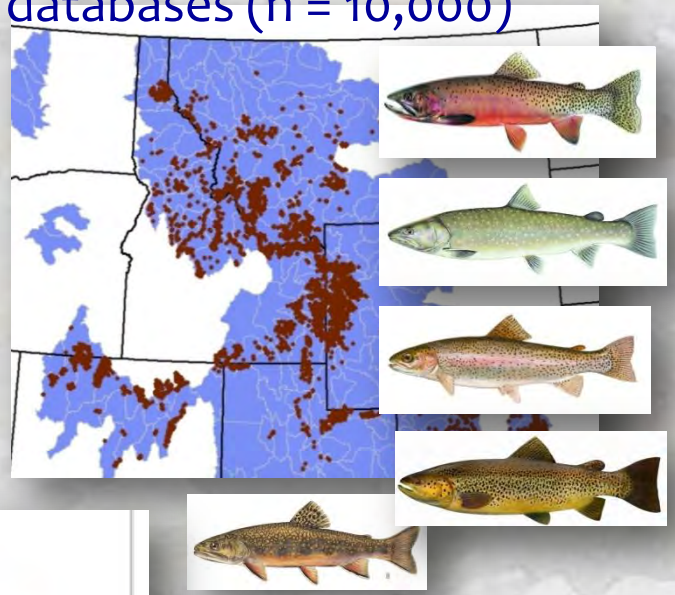
Translating Stream Temperatures to Consistent Thermal Niche Definitions

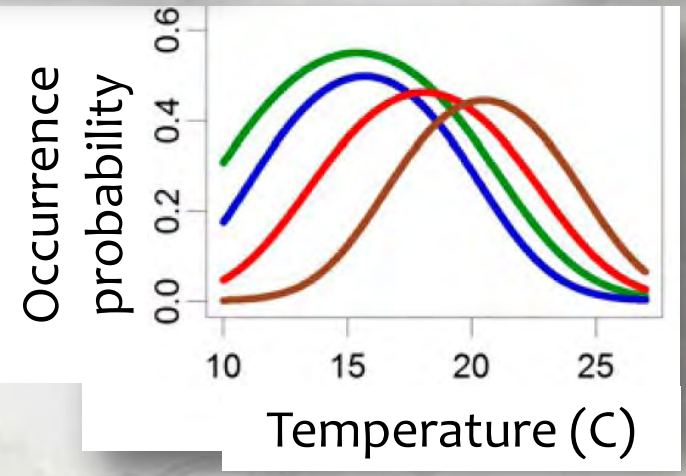
Stream temperature maps



NorWeST Stream Temp

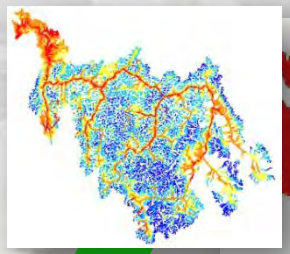
Regional fish survey databases (n = 10,000)

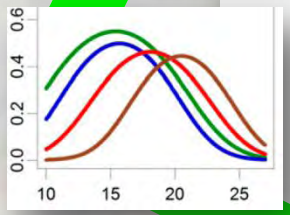




Wenger et al. 2011a. *PNAS* **108**:14175-14180
Wenger et al. 2011b. *CJFAS* **68**:988-1008; Wenger et al., *In Preparation*

Salmon River Bull Trout Habitats



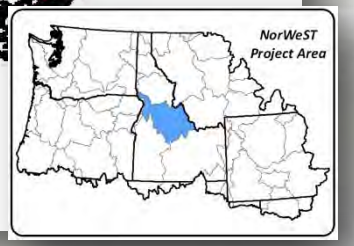


2002-2011 Historical

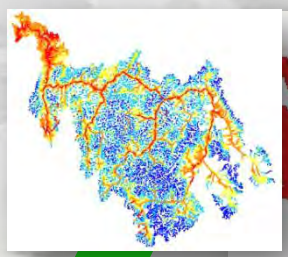
11.2 °C isotherm

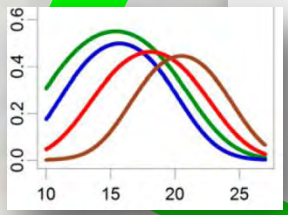
Suitable

Unsuitable



Salmon River Bull Trout Habitats



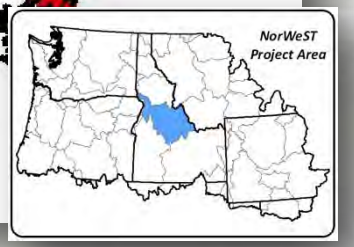


+1°C Stream Temperature

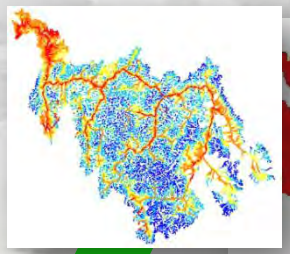
11.2 °C isotherm

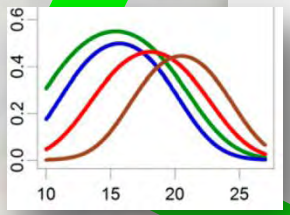
Suitable

Unsuitable



Salmon River Bull Trout Habitats



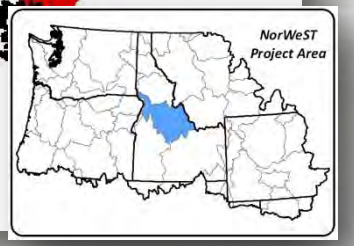


+2˚C Stream Temperature

11.2 ˚C isotherm

Suitable

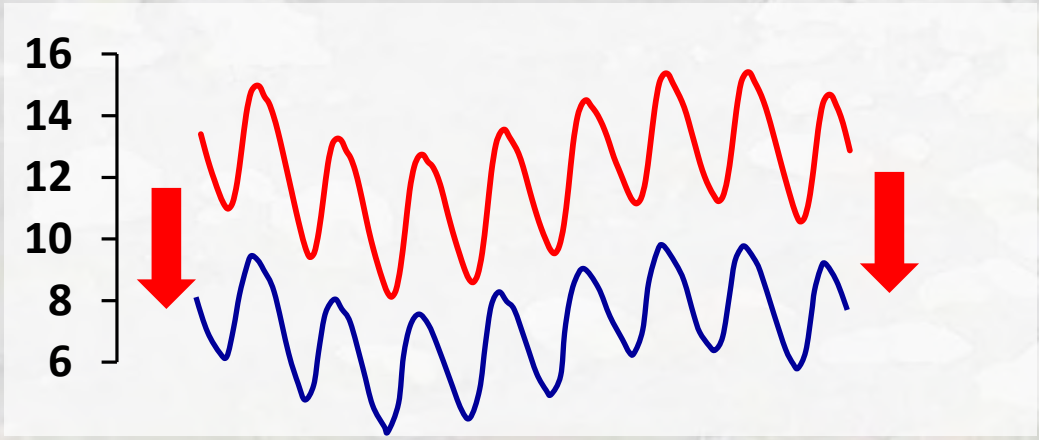
Unsuitable



Application: Quantify Thermal Degradation

What is the thermal "intrinsic potential" of a stream?

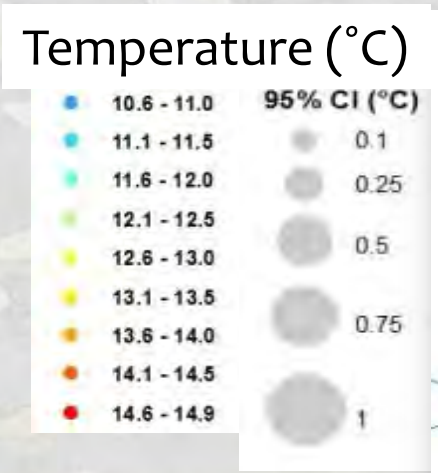
"How much cooler could we make this stream?"

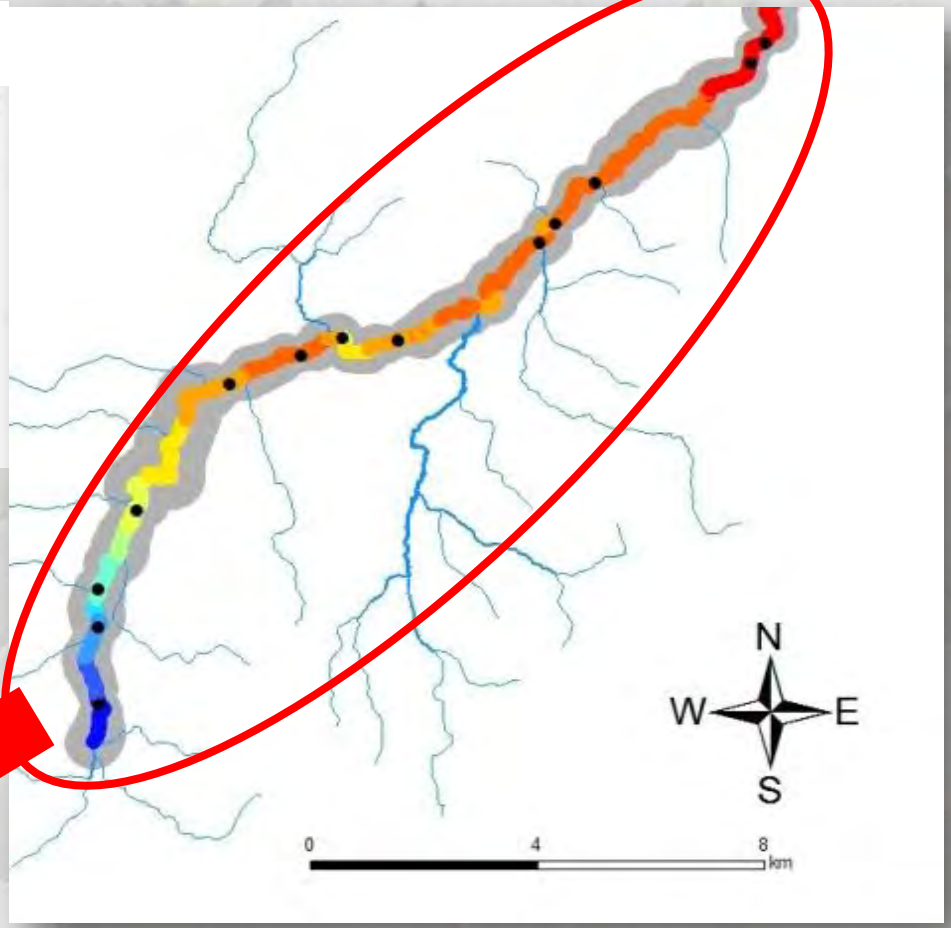


1) Pick "degraded" and "healthy" streams to compare

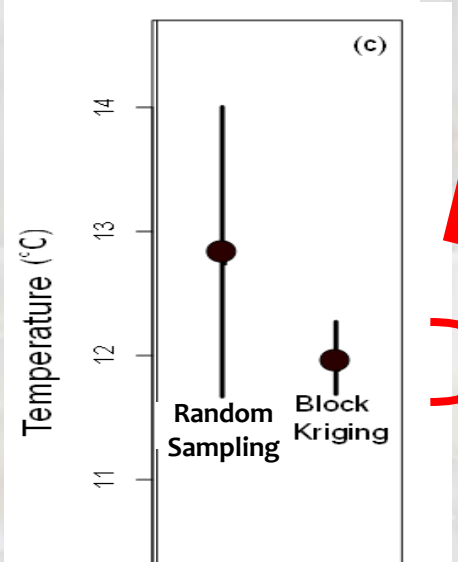
Application: Quantify Thermal Degradation

2) Block-krige estimates of temperature at desired scale





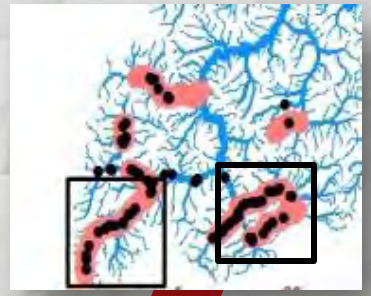
Bear Valley Creek
Mean Temperature

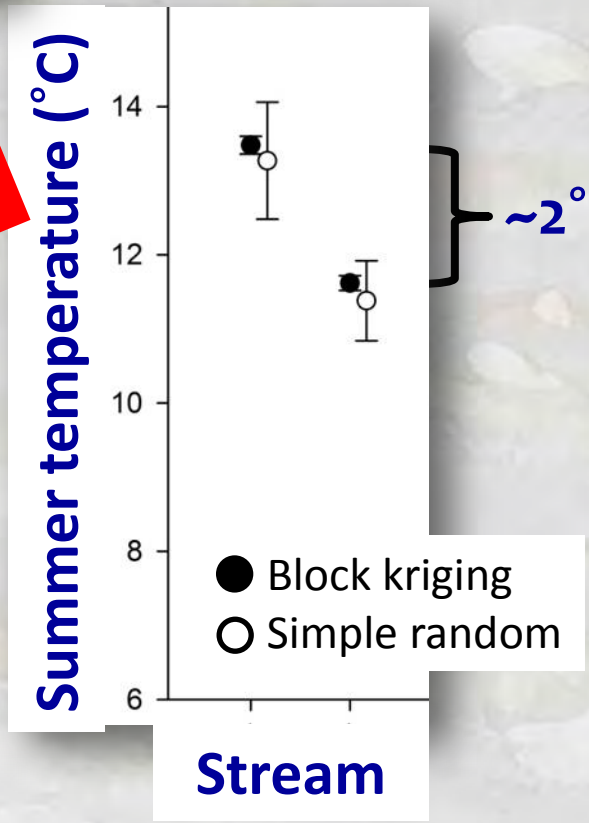


Precise & unbiased estimates

Application: Quantify Thermal Degradation

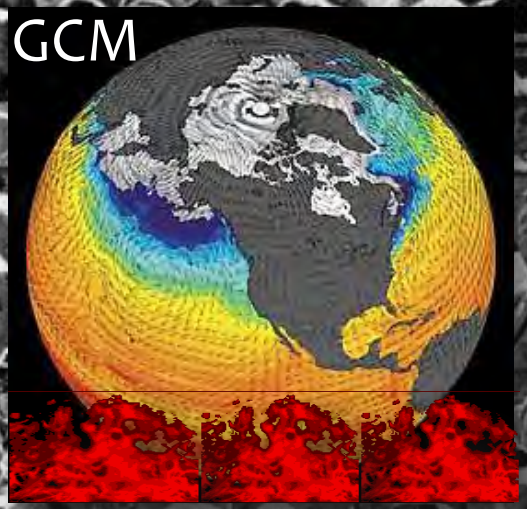
3) Compare estimates among streams

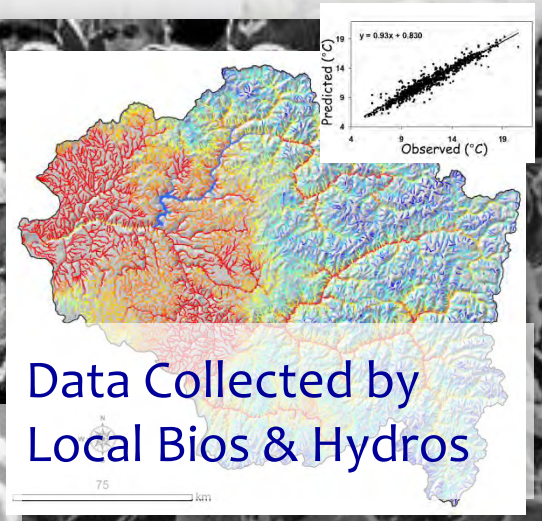




~2°C cooling is possible

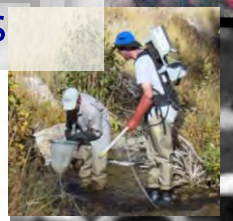
Spatial Models Enable "Crowd-Sourced" Science Because Autocorrelation is OK





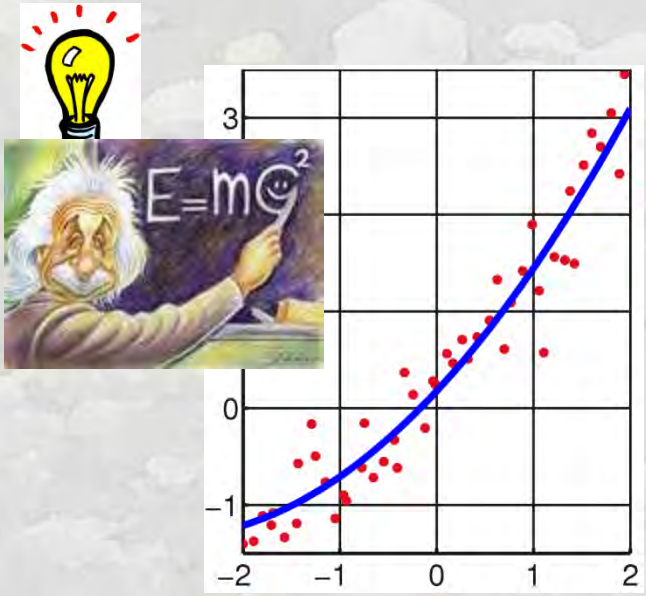
Coordinated, Interagency Responses?

Management Actions

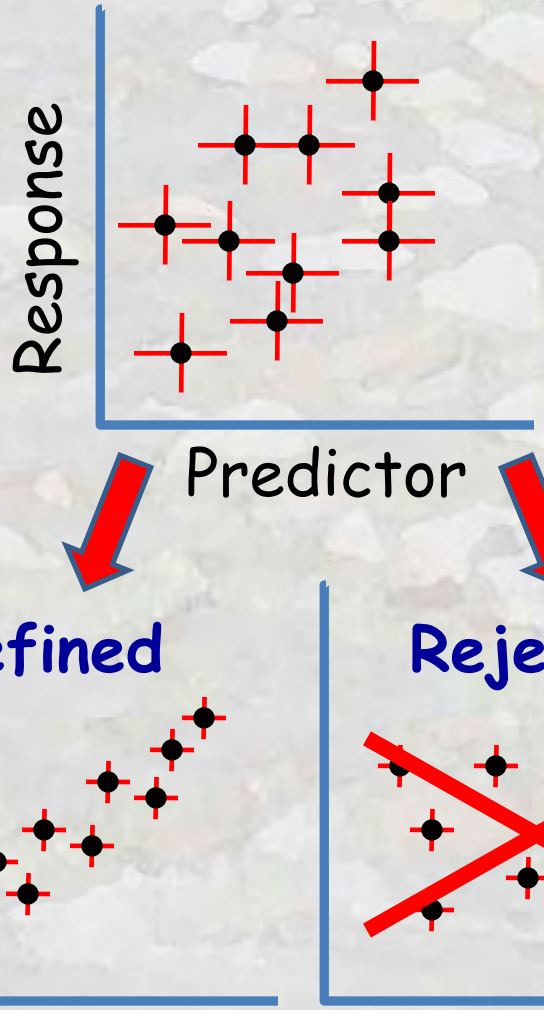


Better Understanding & Prediction from Stream Data

New relationships described



Old relationships tested

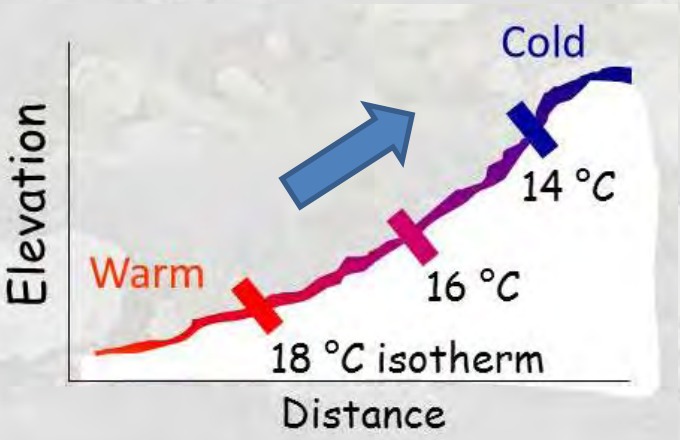


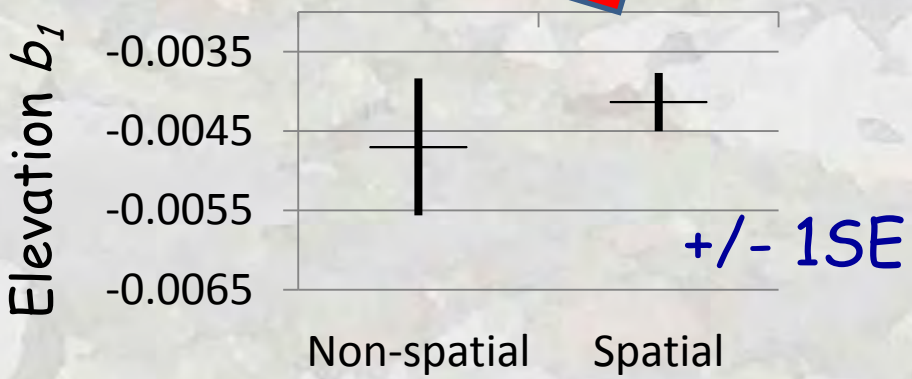
Are Some Streams More Sensitive to Climate Warming than Others?

Not Nearly as Much as People Think…

Temp Model	Non-spatial	Spatial
Boise basin	-0.0064	-0.0045
Payette NF	-0.0036	-0.0034
Lower Snake	-0.0041	-0.0045

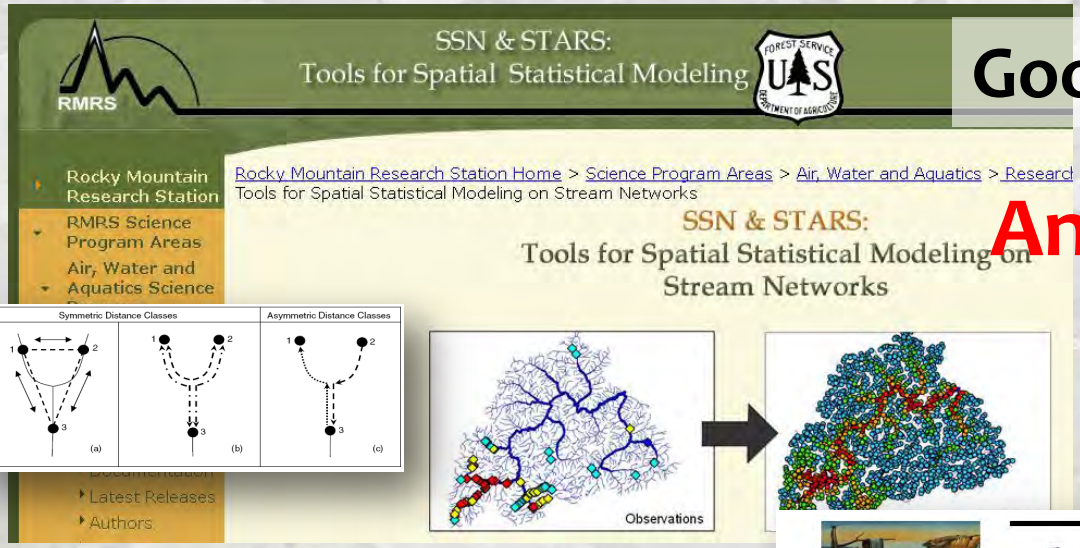
Elevation Parameters (°C / m)





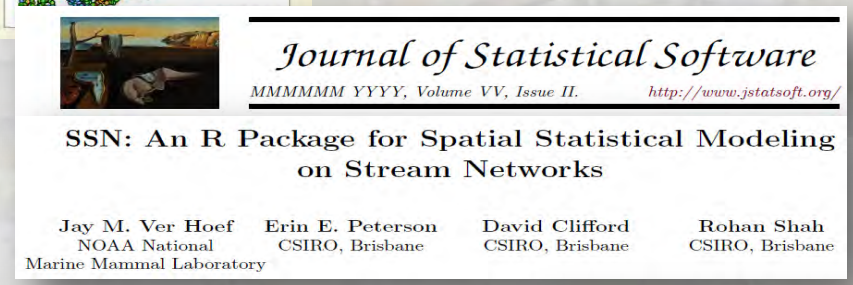
SSN/STARS Website

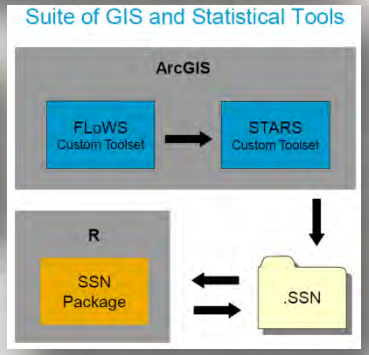
FreeWare Tools, Example Datasets, & Applications



Google "SSN/STARS"

Analytical Stream Ecosystem is Growing





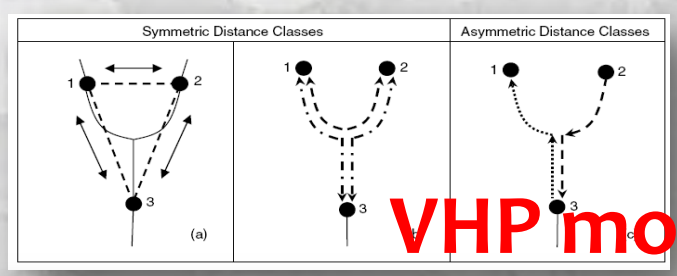
A Moving Average Approach for Spatial Statistical Models of Stream Networks

Jay M. VER HOEF and Erin E. PETERSON

STARS: An ArcGIS toolset used to calculate the spatial data needed to fit spatial statistical models to stream network data

User Community is Growing

>5,000 Visits to SSN/STARS Website in last 7 months



VHP models

National

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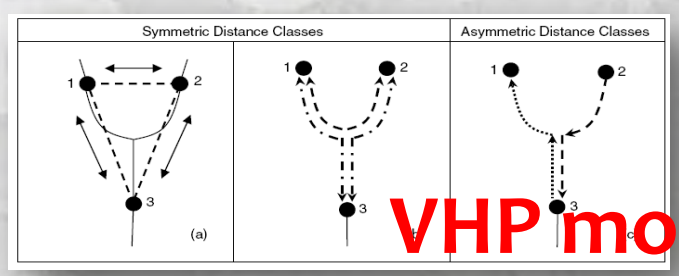

VHP models

Global


The End