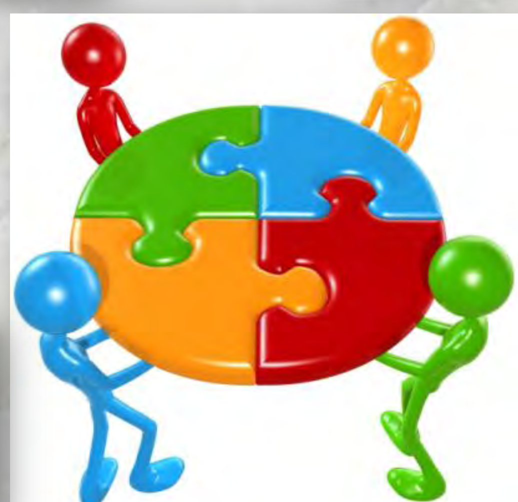
Building a Stream InterNet for Enhanced Conservation & Management of Aquatic Resources

Dave Nagel, Dona Horan, Sharon Parkes, Gwynne Chandler, Sherry Wollrab

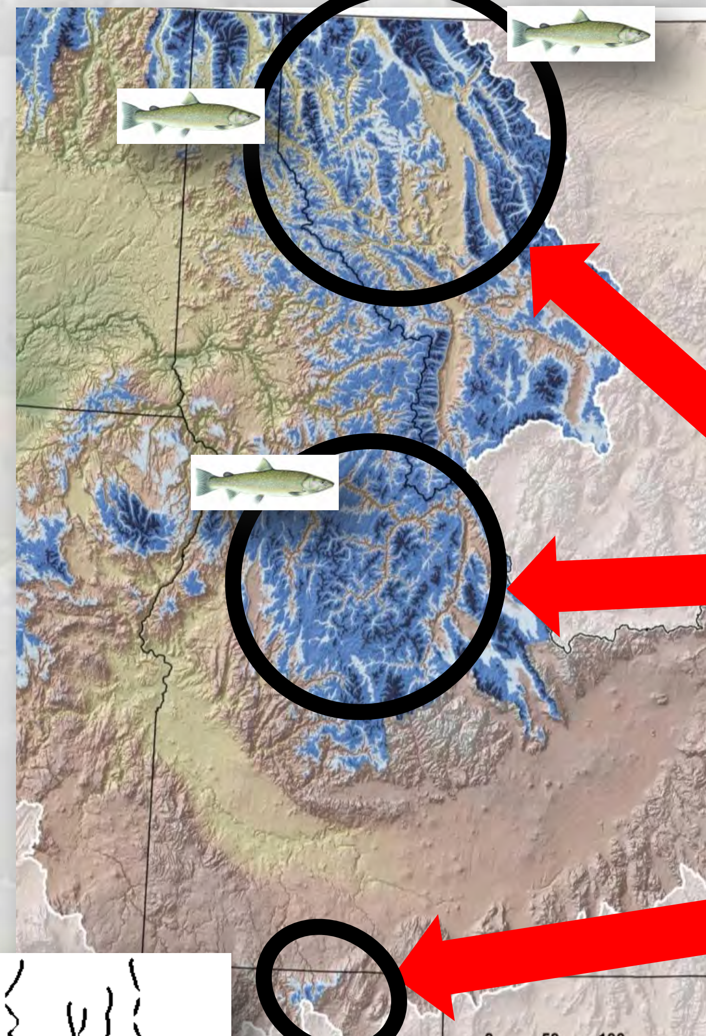
Erin Peterson, Jay Ver Hoef

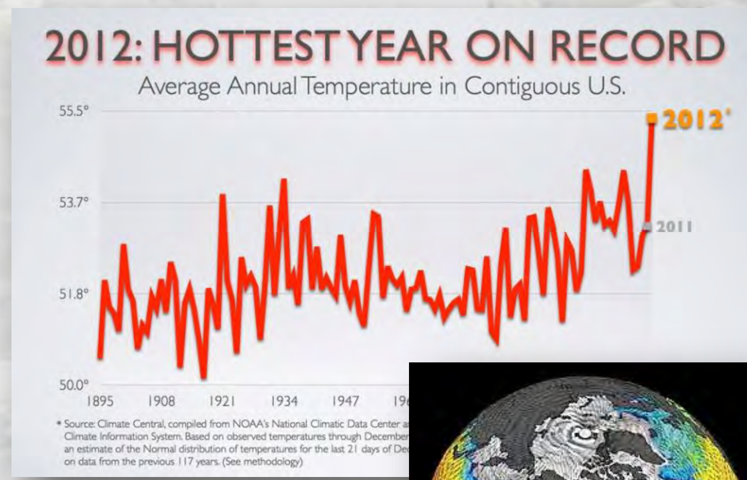
100's of partner –ologists

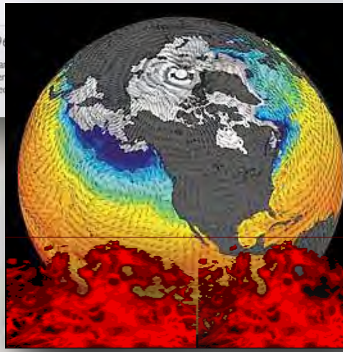


10's of agencies

Better Information Enables Better Decisions, Efficiency, & Resource Stewardship







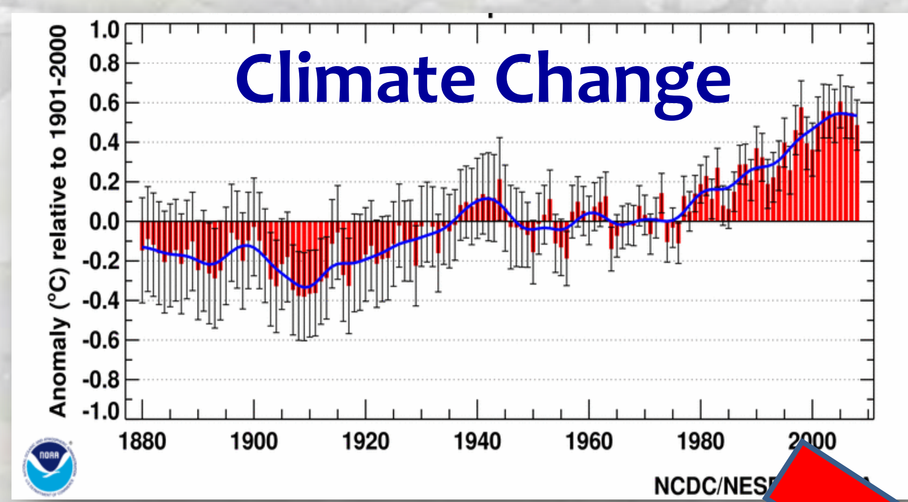
Invest Here

Not here

Sorry Charlie

More Pressure, Fewer Resources

Climate Change



Urbanization & Population Growth

Shrinking Budgets

Need to do more with less

Development of (& Open Access to) Good Information is Critical

"Internet": A networked system capable of transferring massive amounts of information among many participants simultaneously

New Data (what's being "clicked" on?)

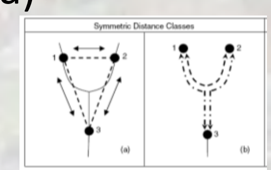
Sensor networks & people on landscapes

Google Servers & Databases

Institutional memory & corporate databases

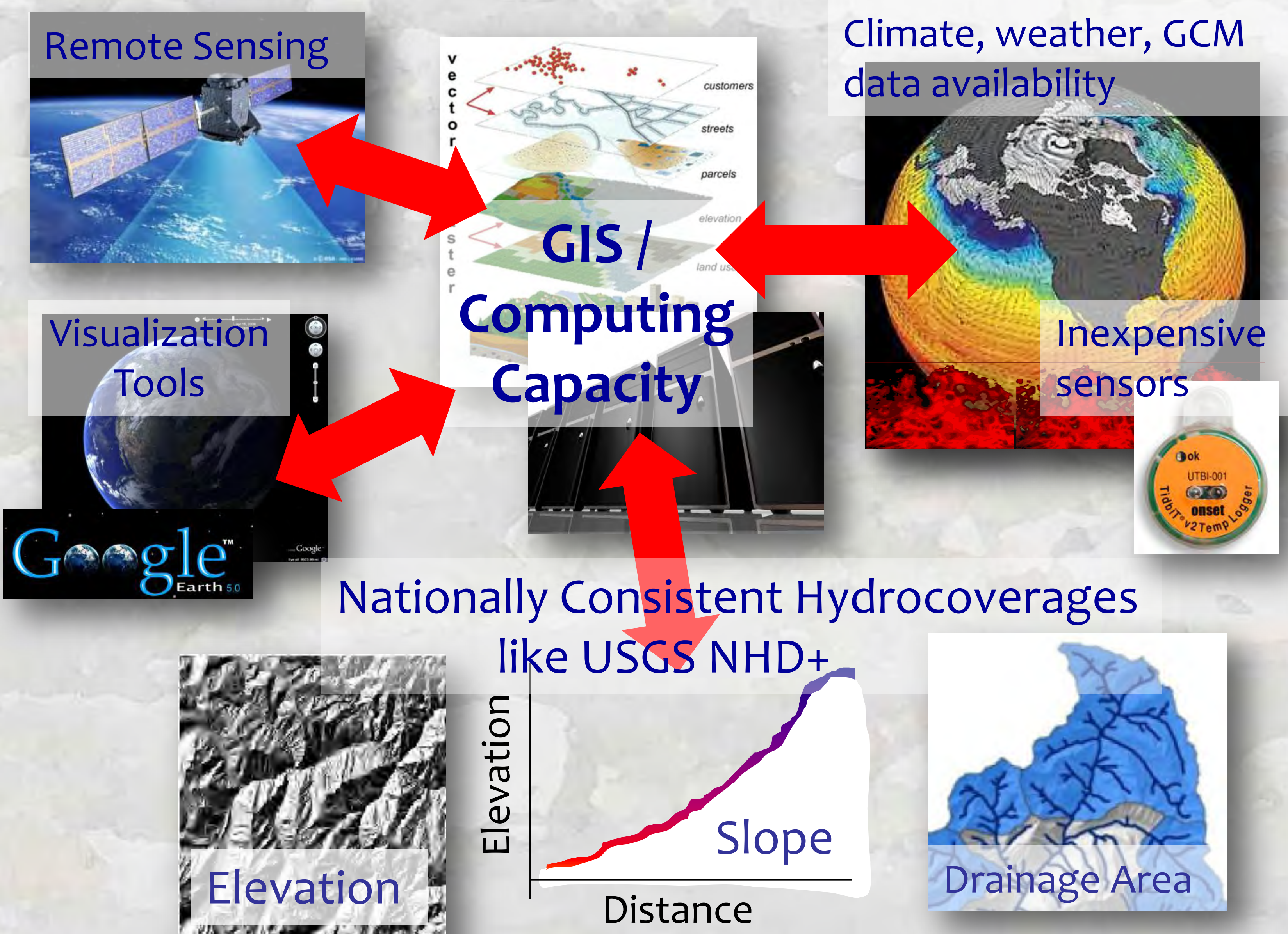
Search algorithms find signal in noise (information from data)

New stream analyses & research branch



Key feature: information flows in many directions

Key Ingredient #1: Geospatial Tools for Accurate Regional Scale Stream



Key Ingredient #2: Spatial Statistical Models for Stream Networks

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

ORIGINAL ARTICLE

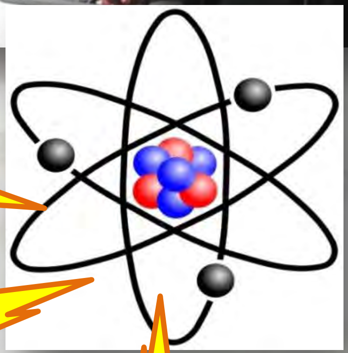
Spatial statistical models that use flow and stream distance

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:
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A. Wade
M.R. Sherburne

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

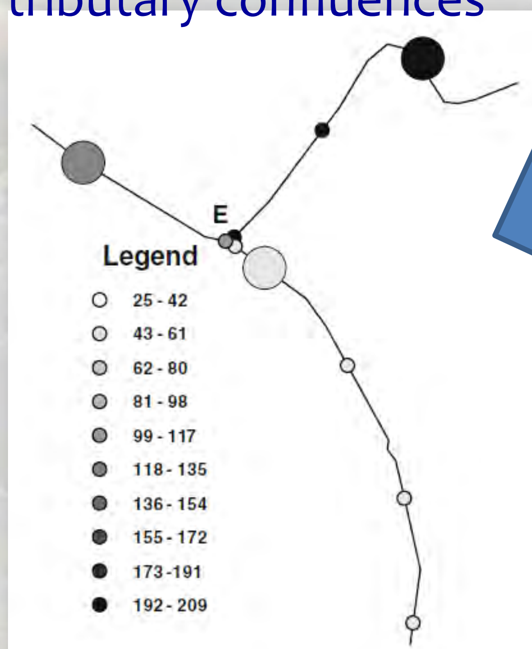
Vincent Garreta[1*,†], Pascal Monestiez[2] and Jay M. Ver Hoef[3]

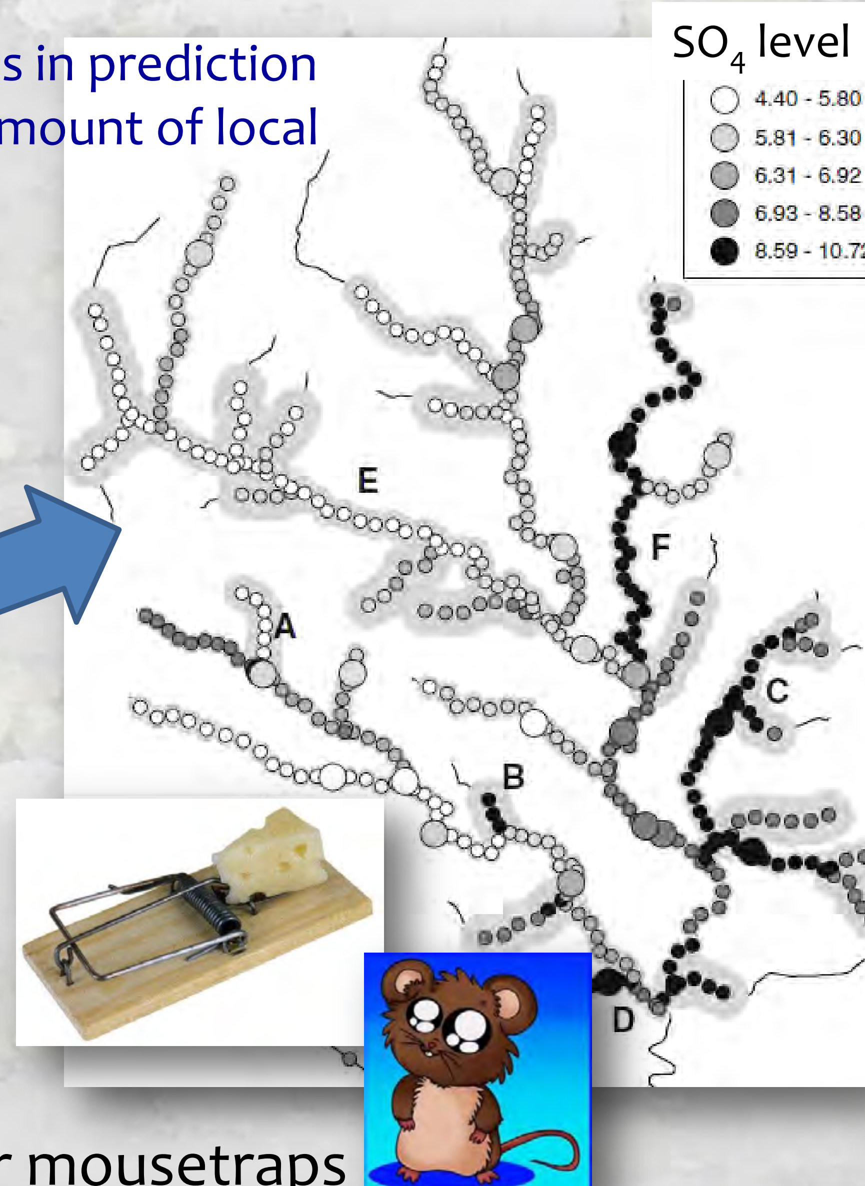
[1]CEREGE, UMR 6635, CNRS, Université Aix-Marseille, Europôle de l'Arbois, 13545 Aix-en-Provence, France
[2]INRA, Unité de Biostatistique et Processus spatiaux, Domaine St Paul, Site Agroparc, 84914 Avignon Cedex 9, France
[3]NOAA National Marine Mammal Lab, Alaska Fisheries Science Center, 7600 Sand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

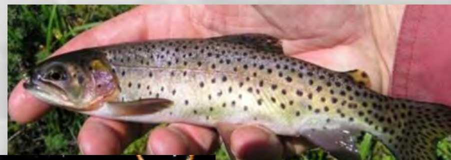
…& represent changes in attributes that occur at tributary confluences





…& are significantly better mousetraps

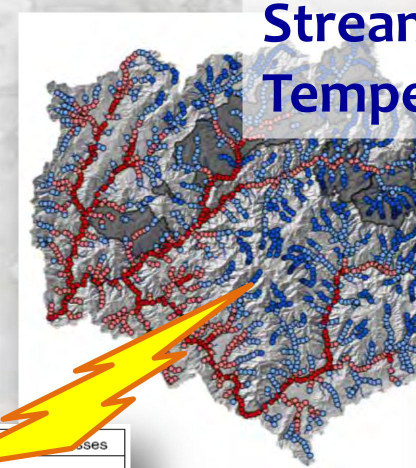
Stream Models are Generalizable…

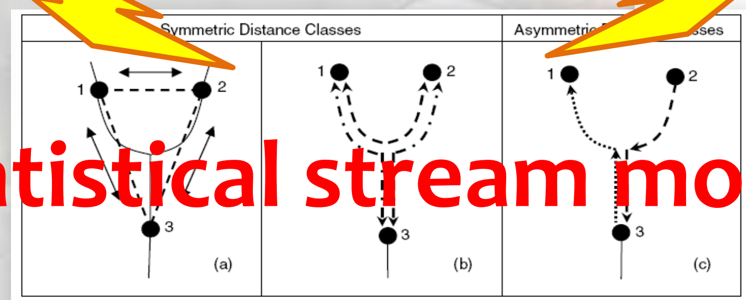


Distribution & abundance

Response Metrics
- •Gaussian
- •Poissan
- •Binomial

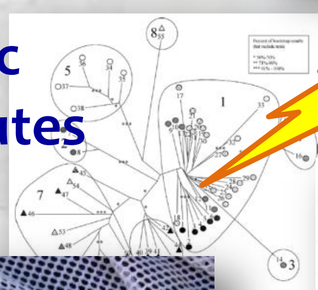
Stream Temperature

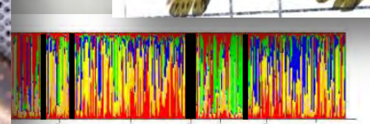




Statistical stream models

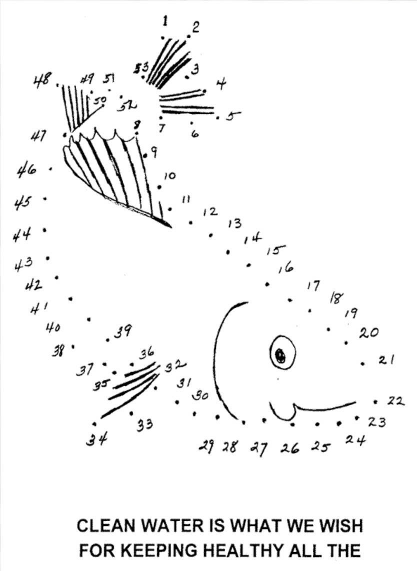
Genetic Attributes



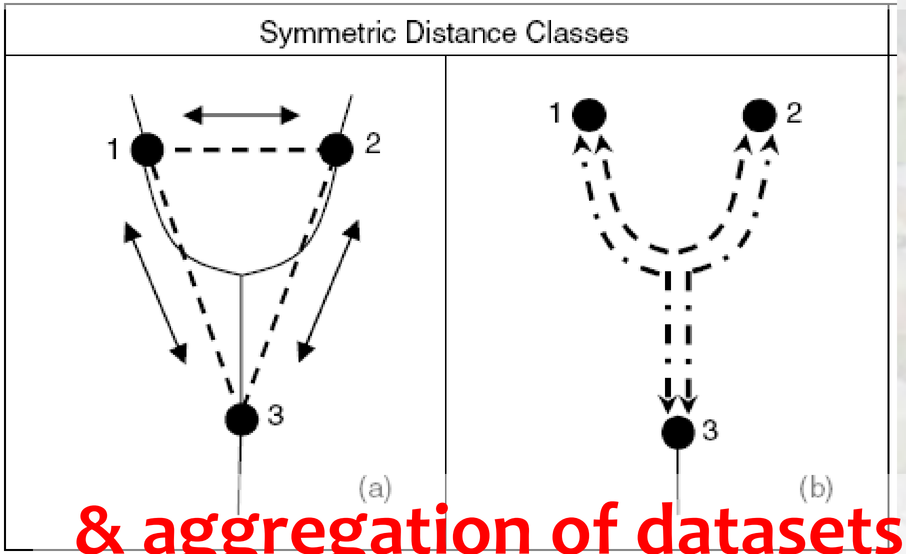


Water Quality Parameters

Spatial Statistical Models are Dot Connectors



Valid interpolation on networks



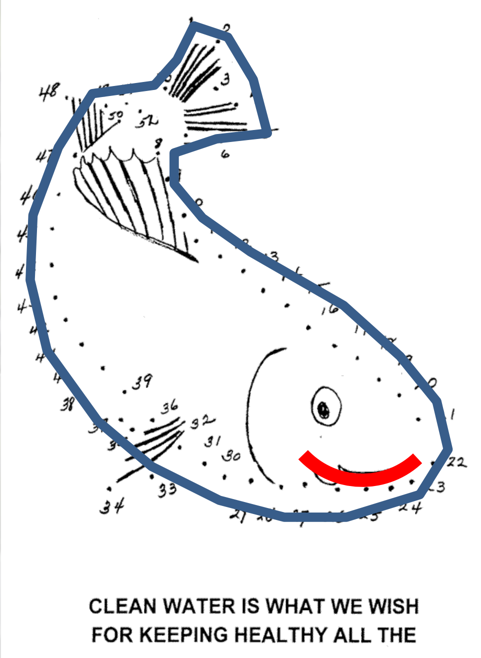
& aggregation of datasets

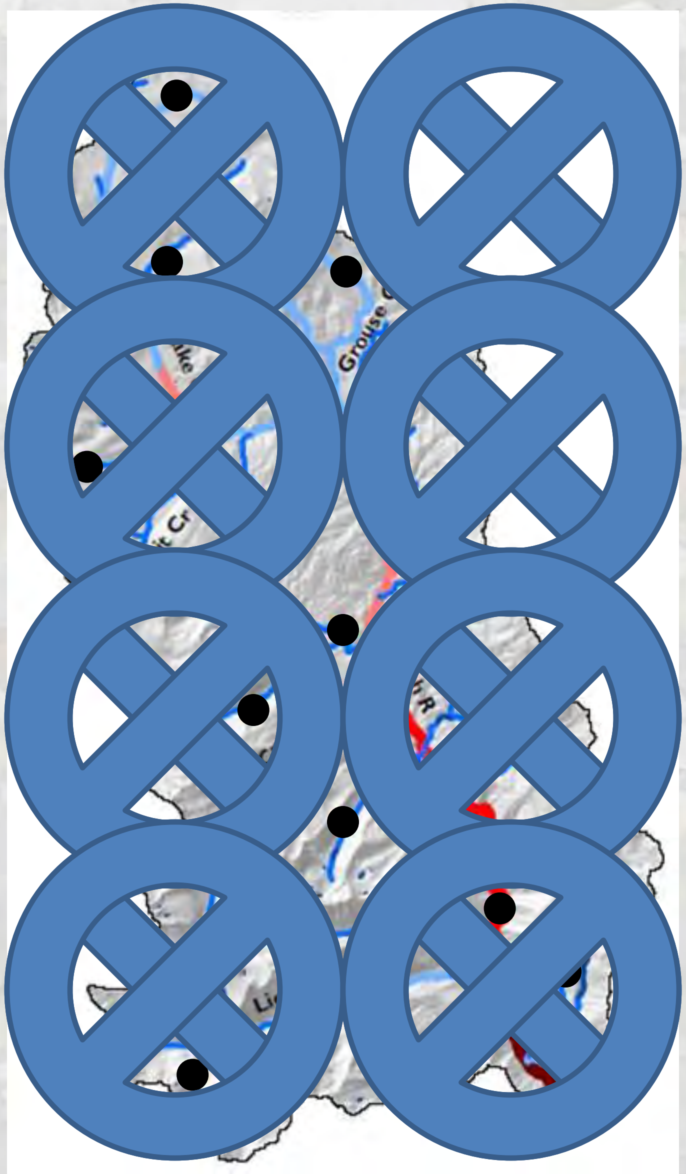
Advantages:

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

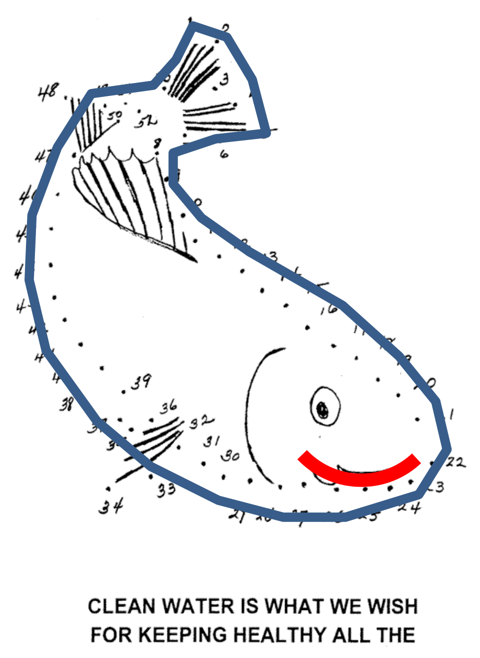
Peterson et al. 2006; Ver Hoef et al. 2006; Ver Hoef and Peterson 2010

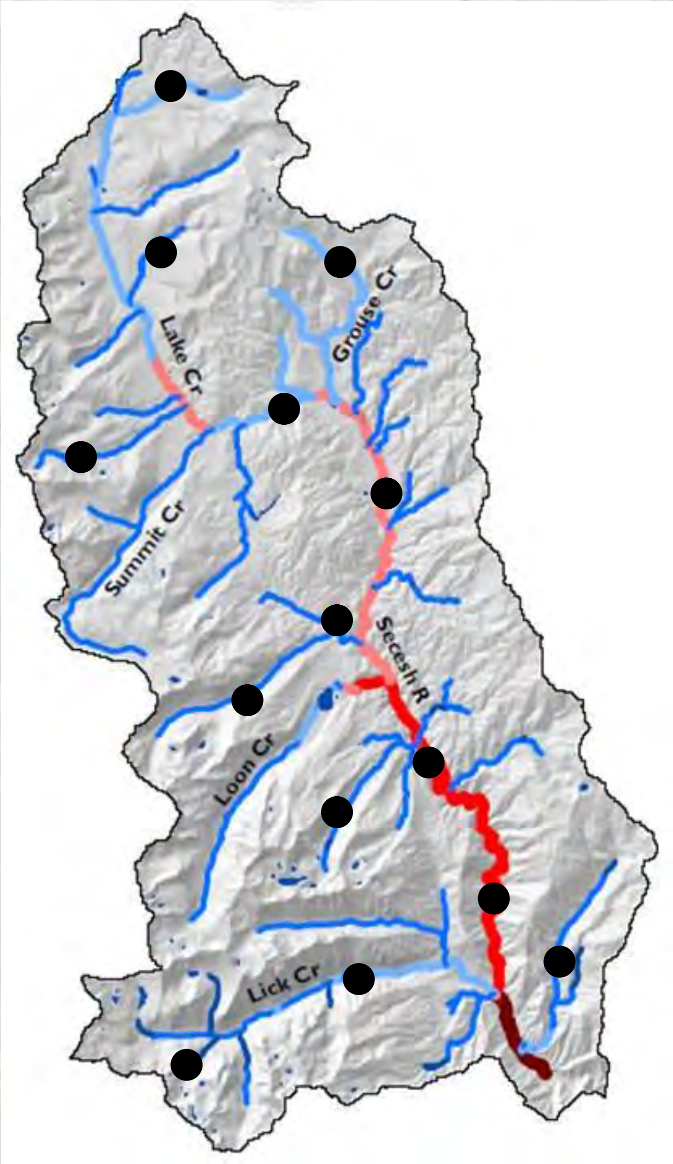
Stop Viewing Streams as Dots





Stop Viewing Streams as Dots





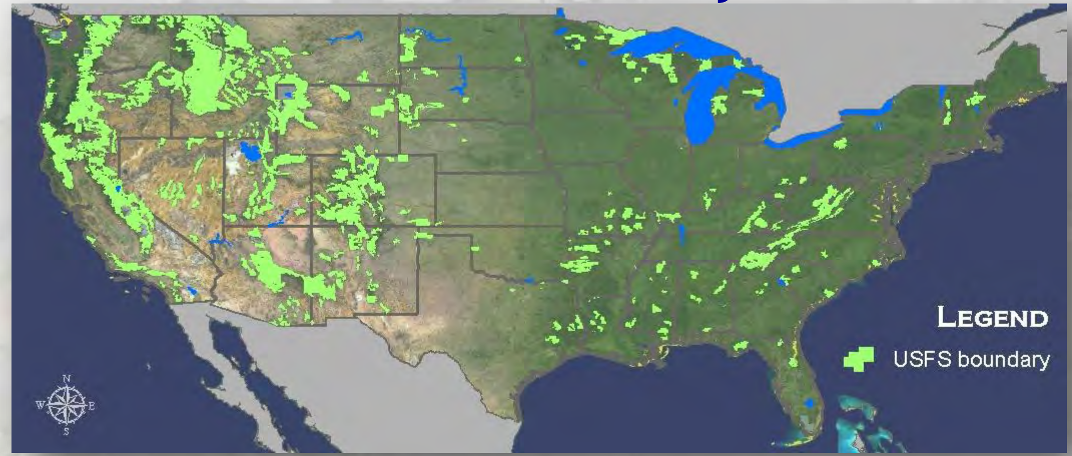
“Smart” Maps Developed from Data

Good Maps Significantly Reduce Uncertainty

We need to make this generation’s maps showing aquatic resource status

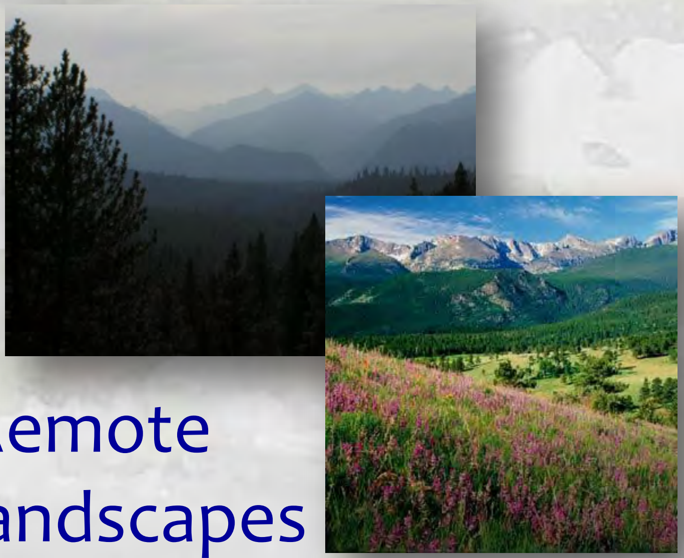
Consistent, Accurate Information Needed Across Broad Areas

Lands Administered by USFS



- 193 Million Acres (10% of US)
- 155 National Forests
- 500,000 stream kilometers

Diverse streams

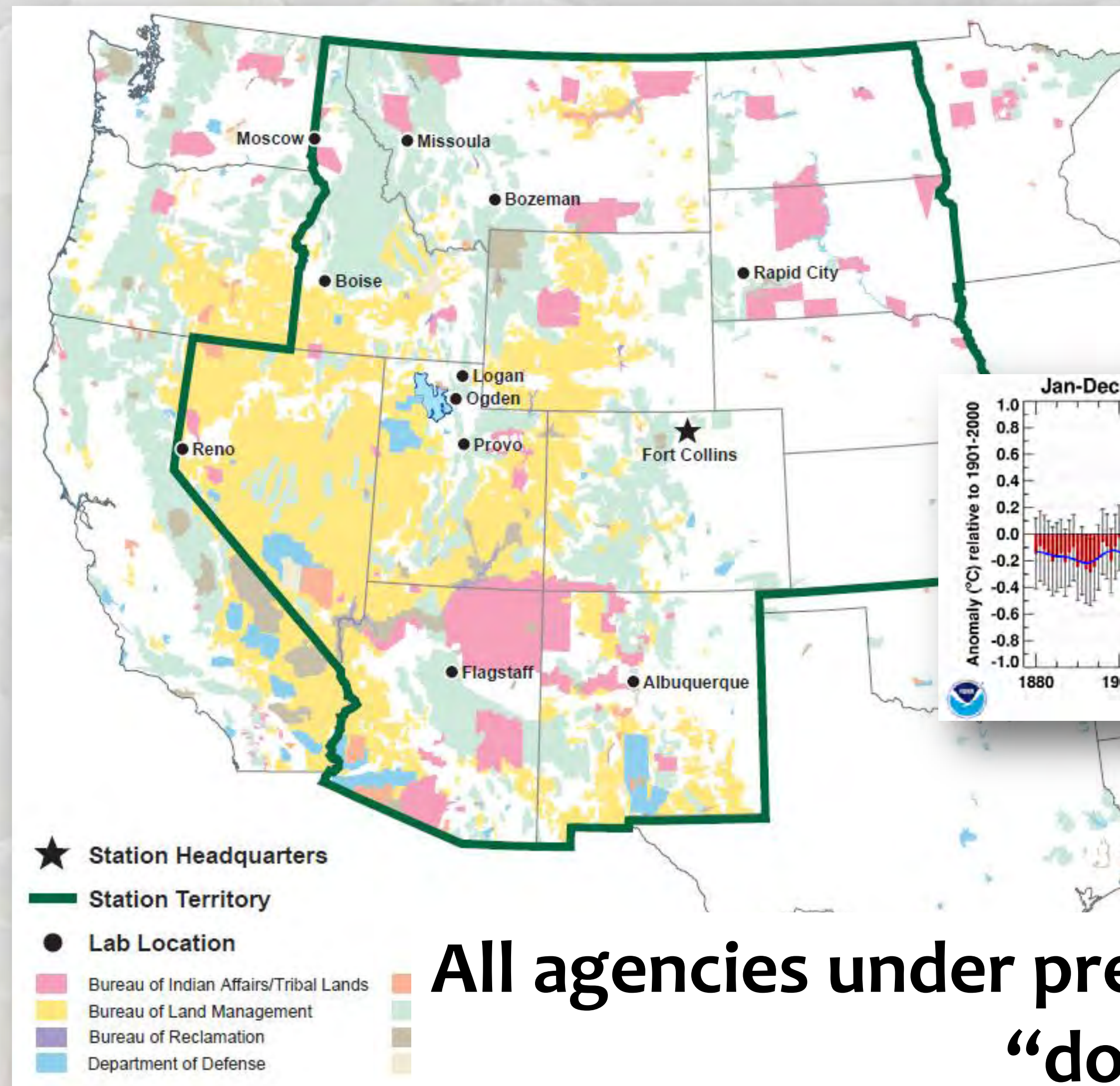


Remote landscapes

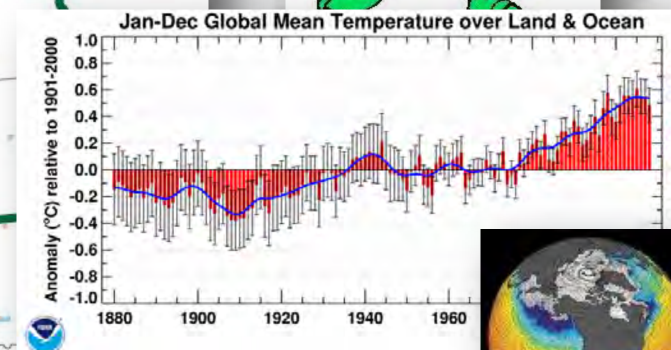
Where do Fish Fit in a Terrestrial World?

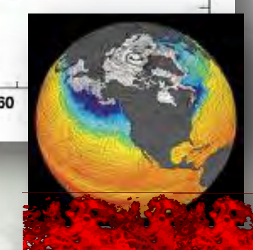
This is a Tree not a Fish

Consistent, Accurate Information Needed Across Agencies



Climate Boogeyman



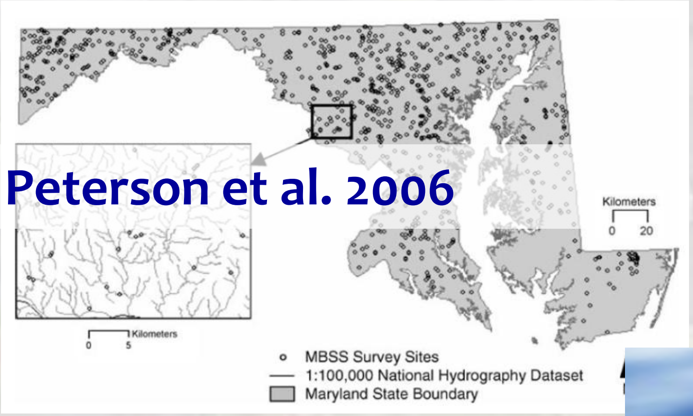


All agencies under pressure to "do something"…

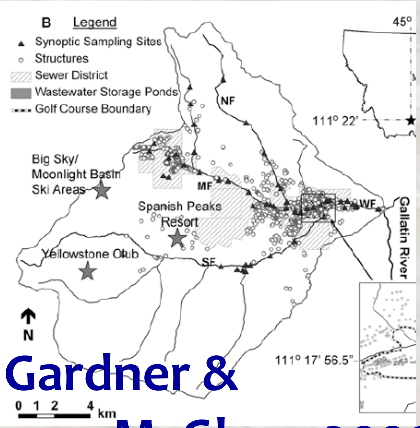
Key Ingredient #3: Existing Databases

Water Quality/Chemistry Information

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

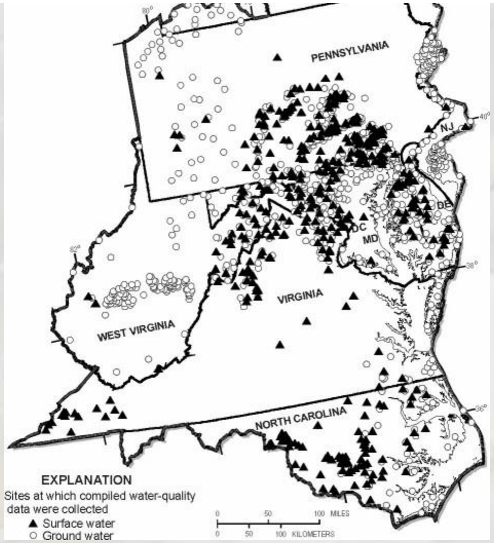


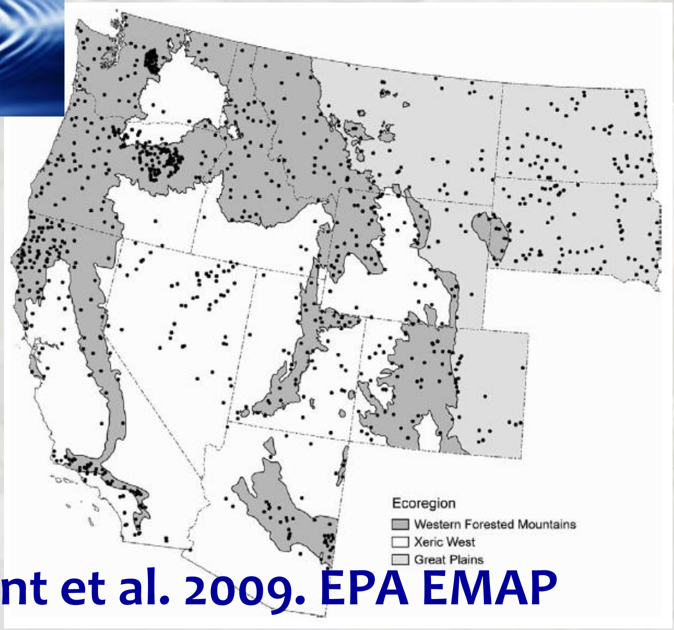
Peterson et al. 2006



Gardner & McGlynn 2009

USGS, unpublished



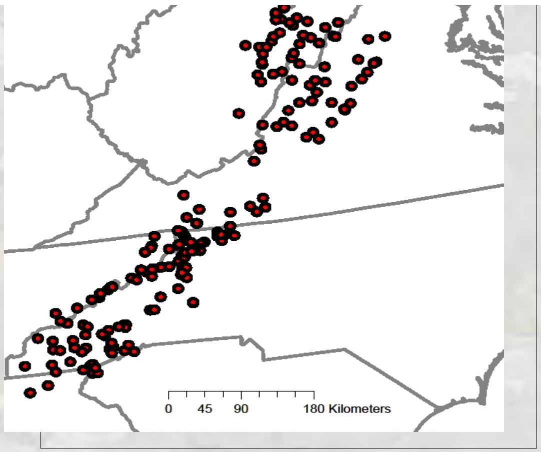


Pont et al. 2009. EPA EMAP

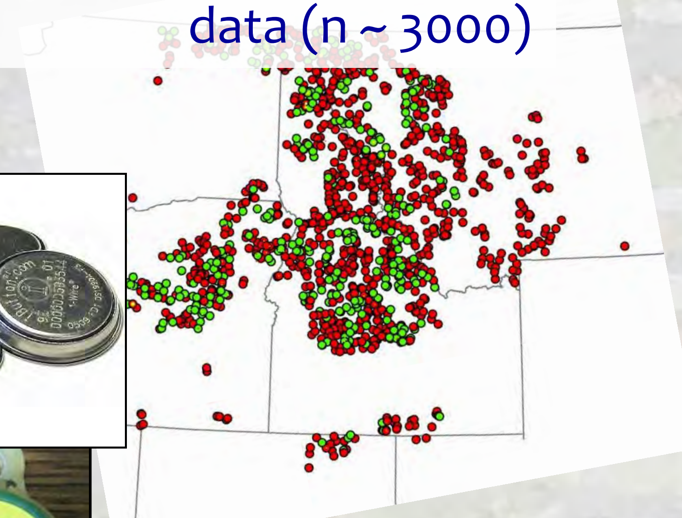
Harnessing Existing Databases

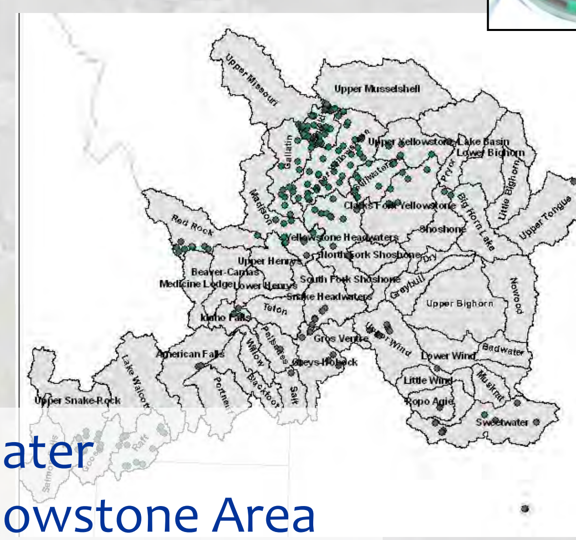
Stream Temperatures

Eastern Brook Trout
Temp Sensor (n ~ 200)

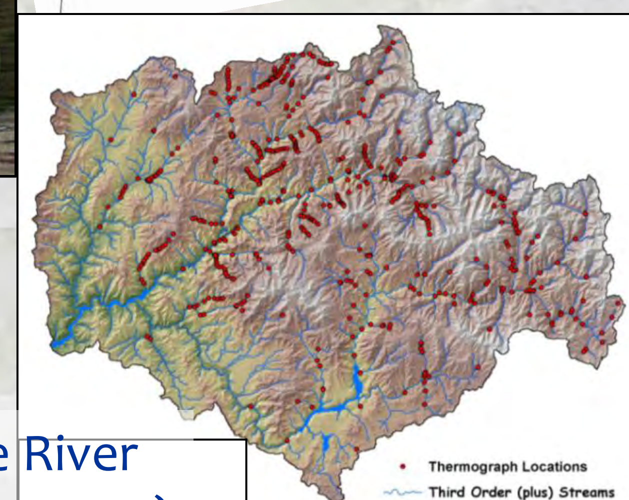


USFS PIBO
data (n ~ 3000)





Greater
Yellowstone Area

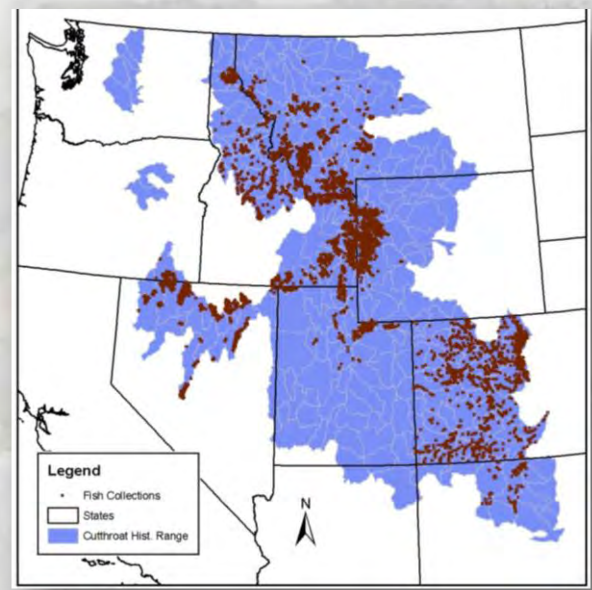


Boise River
(n ~ 1,000)

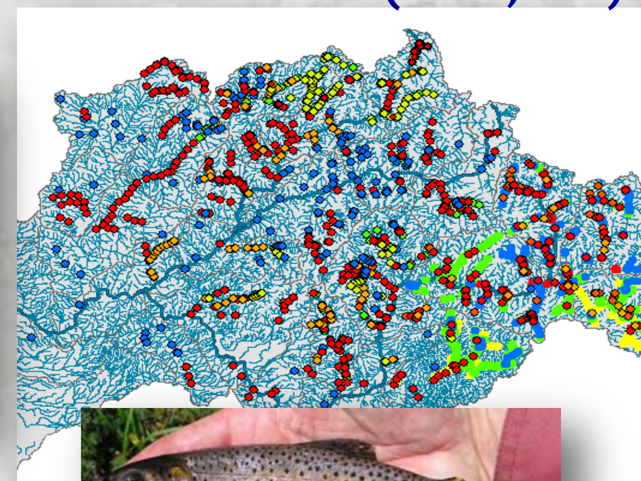
Harnessing Existing Databases

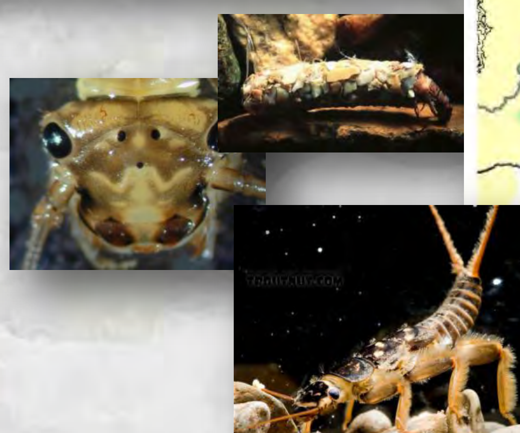
Distribution & abundance of critters

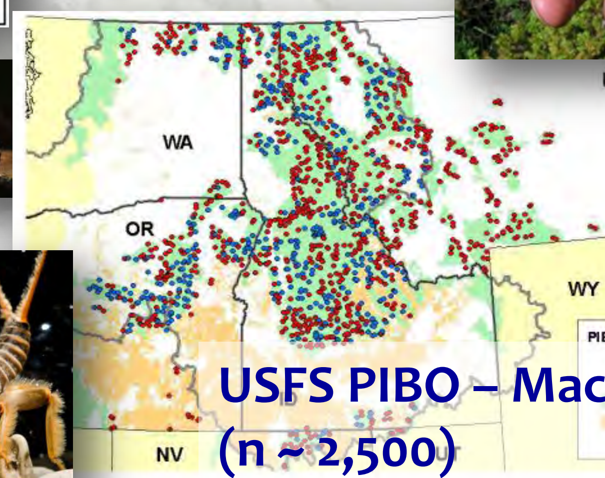
Rocky Mountain Trout database (n ~ 10,000)



Boise basin fish database (n ~ 2,000)

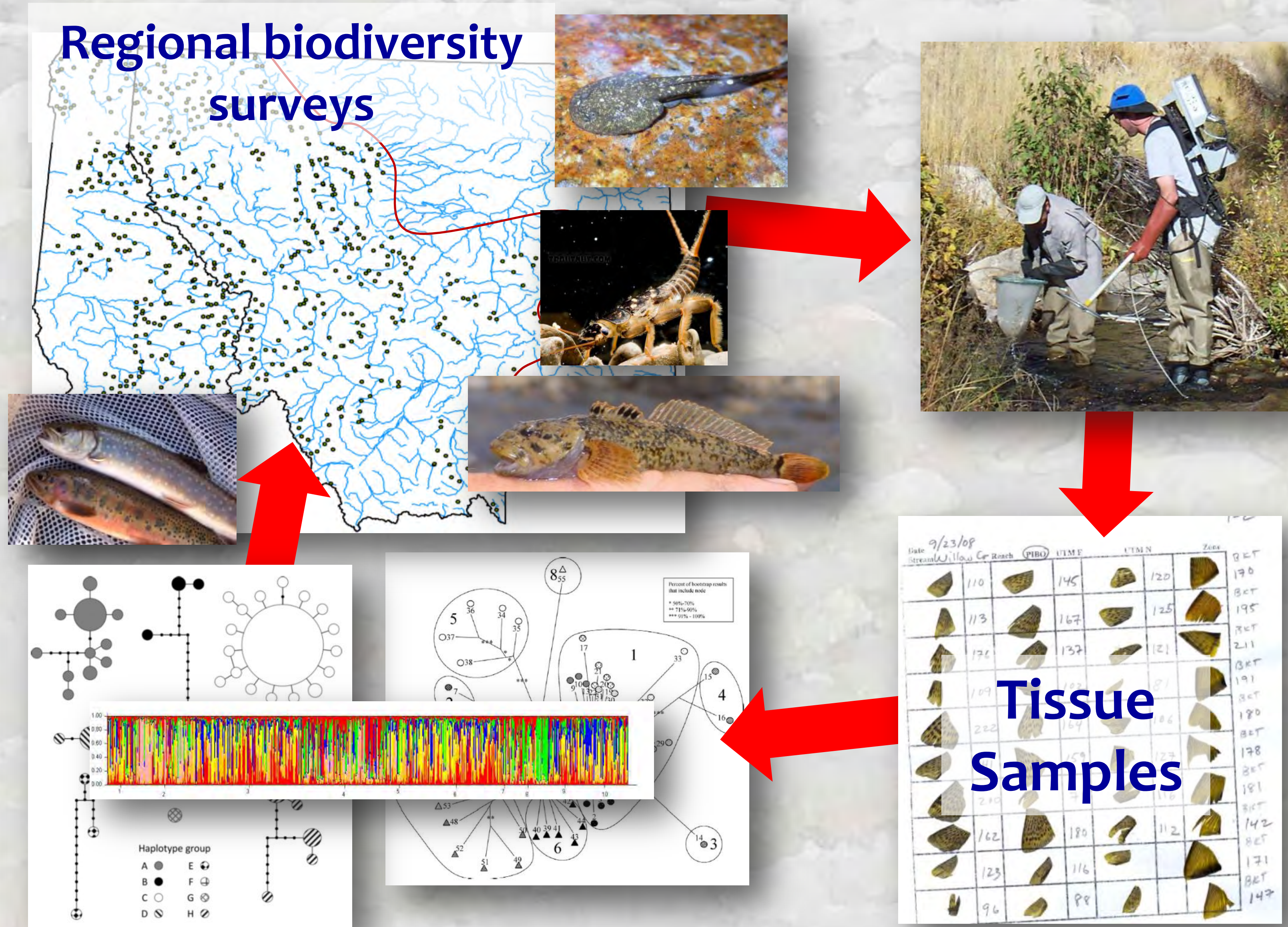






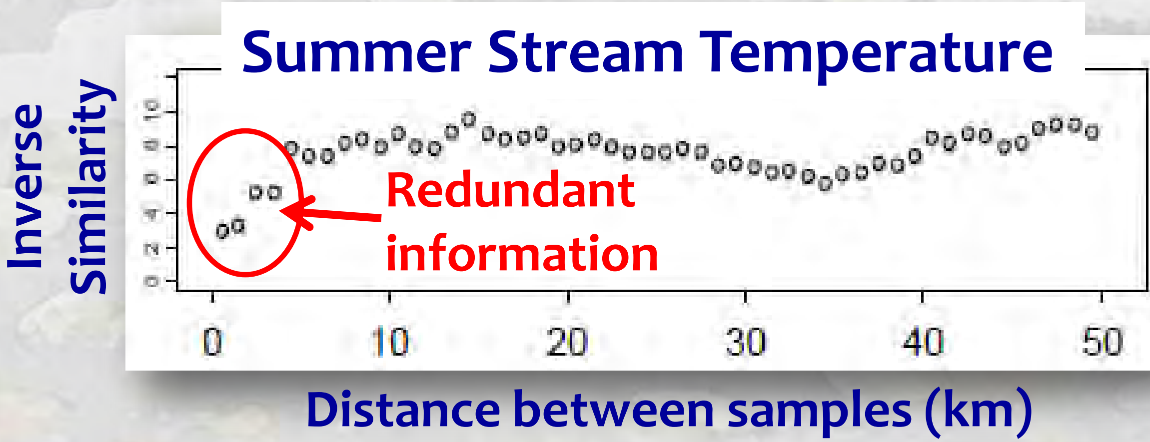
USFS PIBO – Macroinvertebrates (n ~ 2,500)

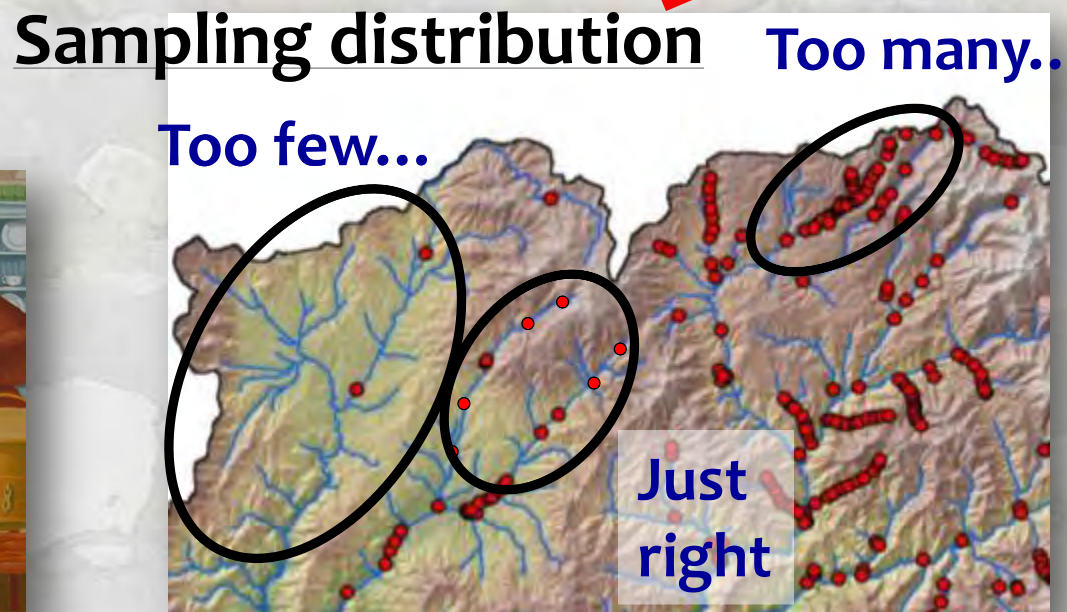
Lots of Genetic Data Coming…



Young et al. 2013; Schwartz et al. 2007; Campbell et al. 2012

Where Data are Sparse, Spatial Models Can Guide Efficient Monitoring Design





A Stream InterNet is Possible

Technology exists. Spatial stream models, computing horsepower, & geospatial technologies provide the basic “routers, switches, servers, and search algorithms” to develop & transfer massive amounts of accurate information about stream resources.

Needed. All agencies experiencing declining budgets & need to do more with less. Also have mandates to address overarching, cross-boundary threats posed by climate change & human population growth.

Scalable. Nationally available geospatial data, growing aquatic databases, & large customer base comprised of natural resource stewards from dozens of resource organizations across the country.

Wanted. New & useful information developed from data that local resource stewards collected. “Killer Apps” can be designed to translate information into formats that empower local decision makers.

Costs. Minimal

Value. Priceless. How do you value good information?

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

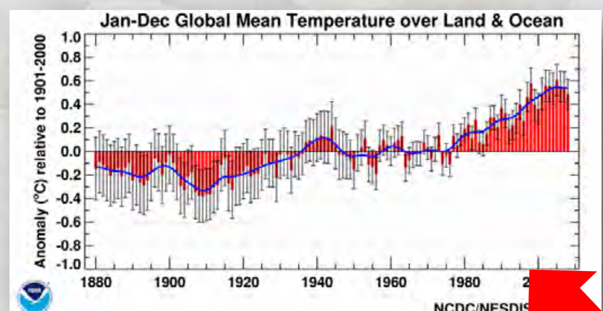
U.S. Forest Service

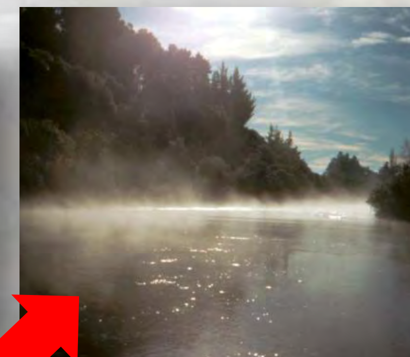
[1]Trout Unlimited

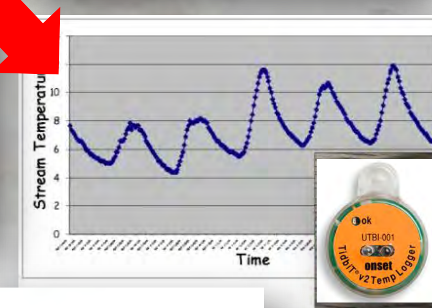
[2]CSIRO

[3]NOAA

[4]USGS





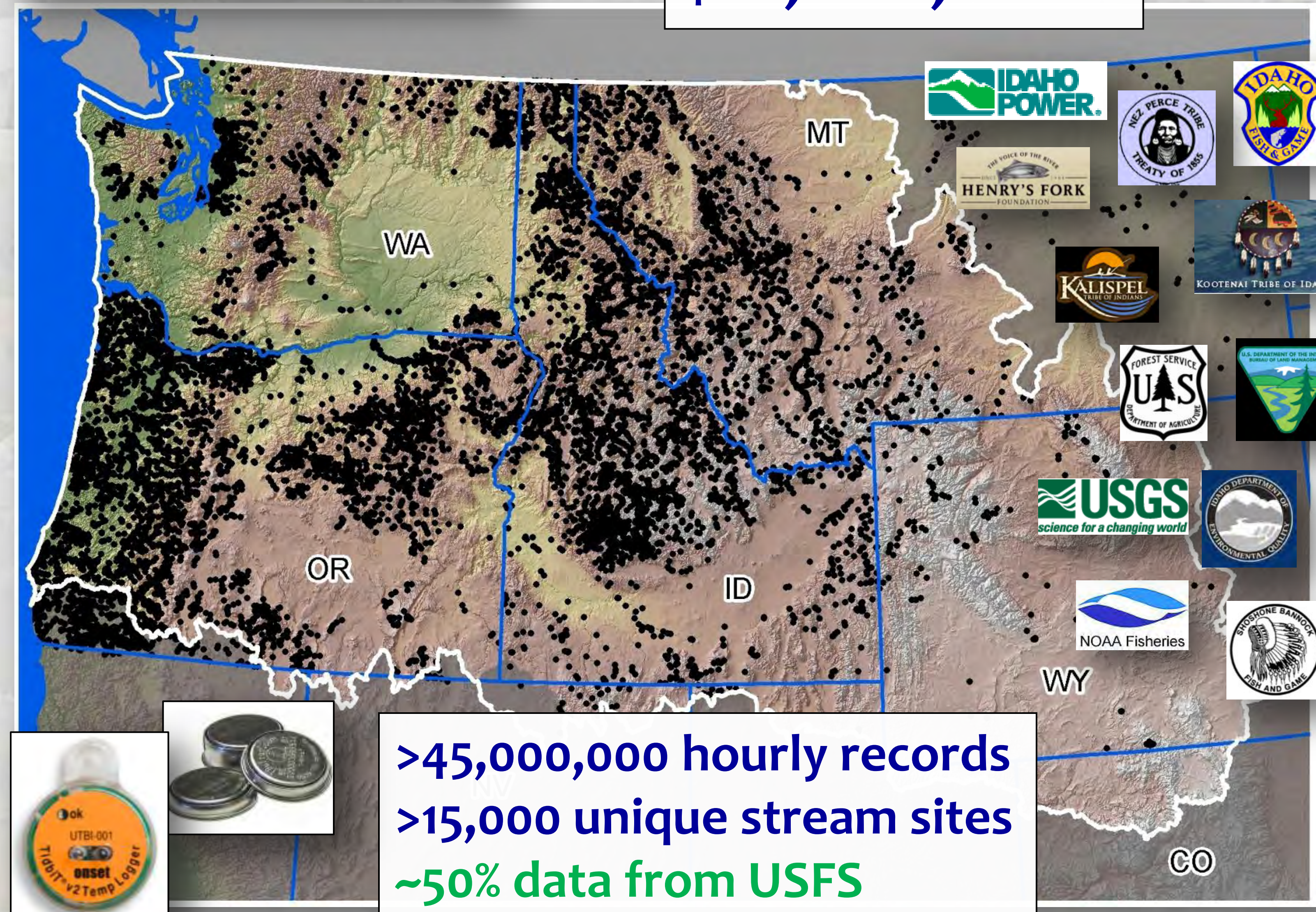


science for a changing world

Great Northern LANDSCAPE CONSERVATION COOPERATIVE

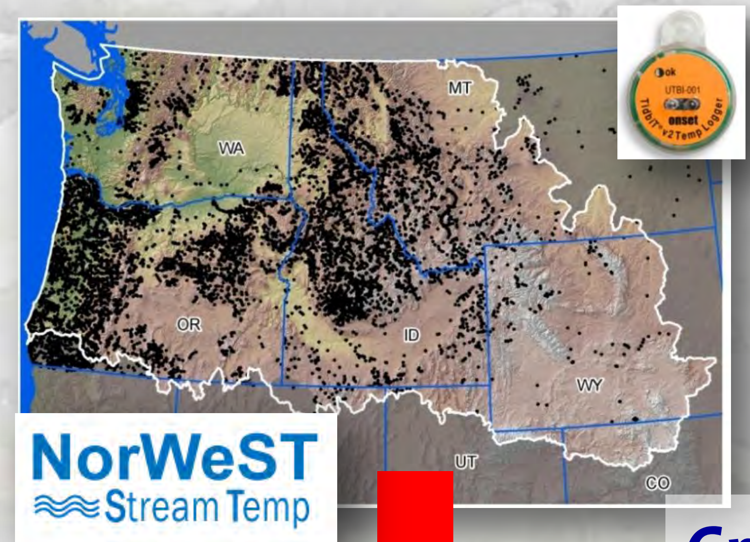
NorWeST Stream Temp

>60 agencies
$10,000,000

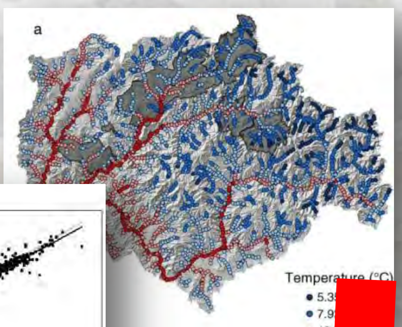


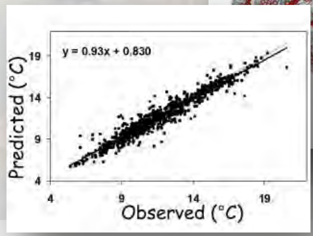
>45,000,000 hourly records
>15,000 unique stream sites
~50% data from USFS

Regional Temperature Model

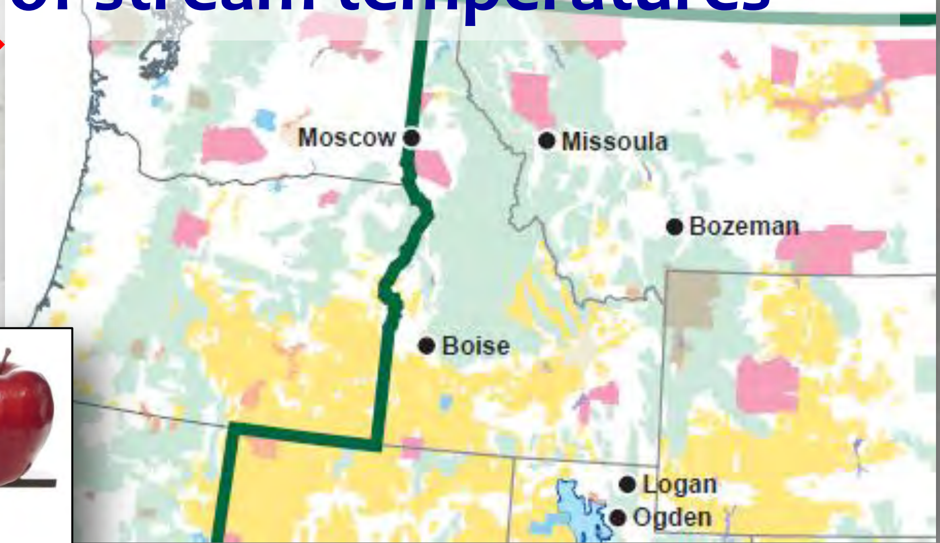


Accurate temperature models

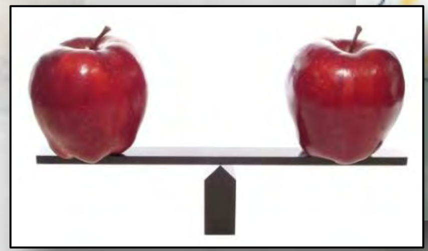




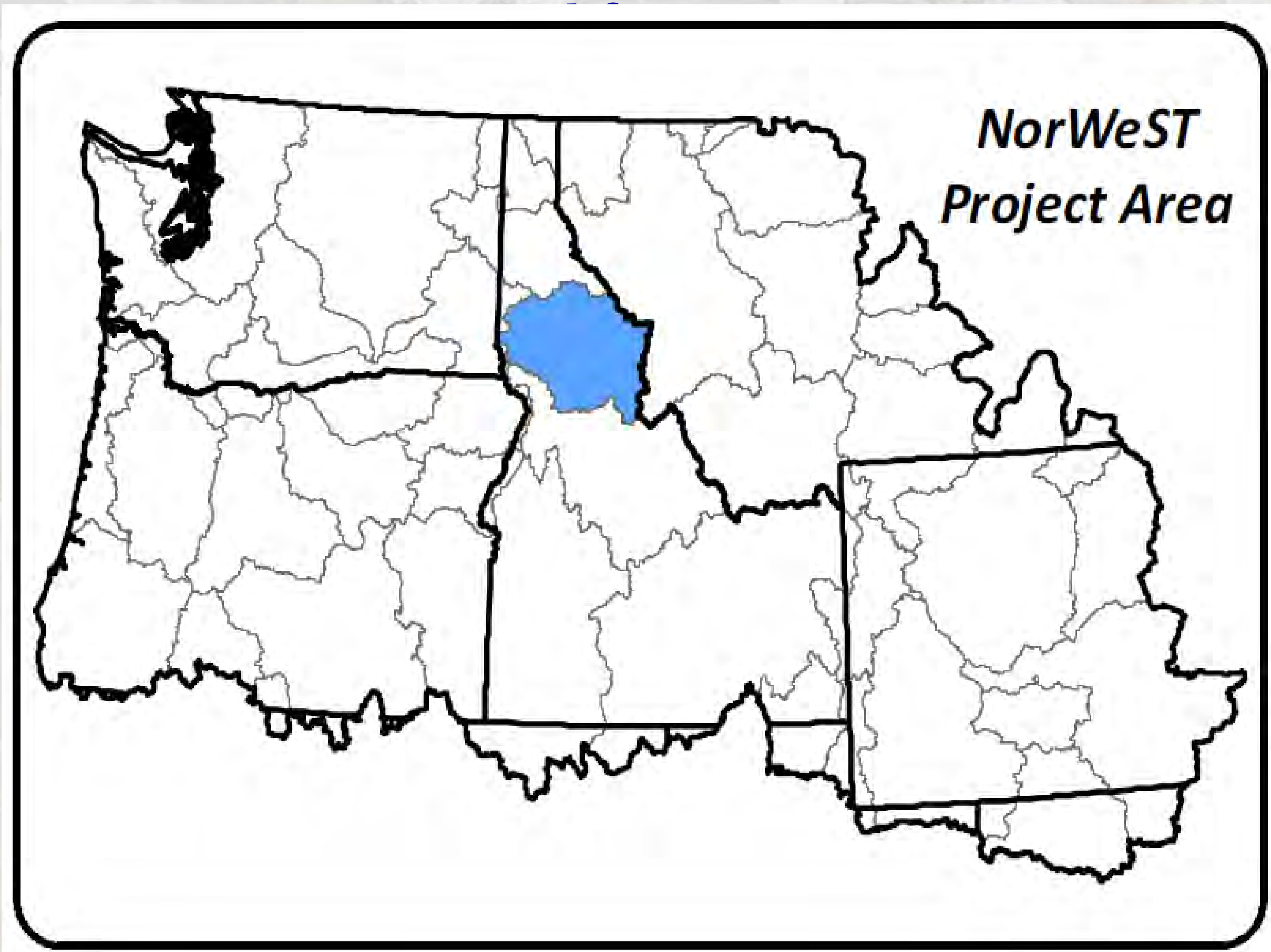
Cross-jurisdictional "maps" of stream temperatures



Consistent datum for strategic assessments across 350,000 stream kilometers



Example: Clearwater River Basin

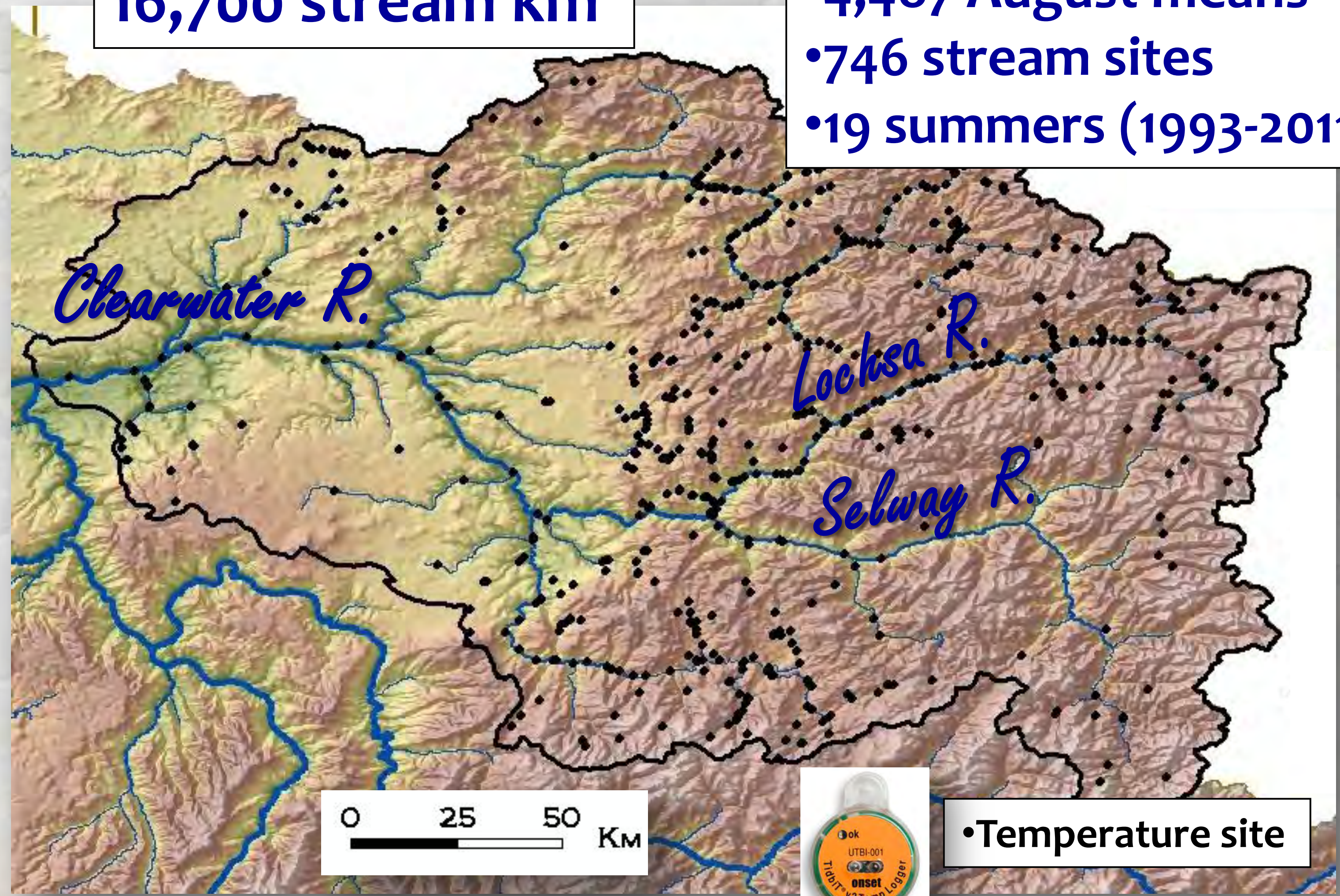


Example: Clearwater River Basin

Data extracted from NorWeST

16,700 stream km

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



•Temperature site

Clearwater River Temp Model

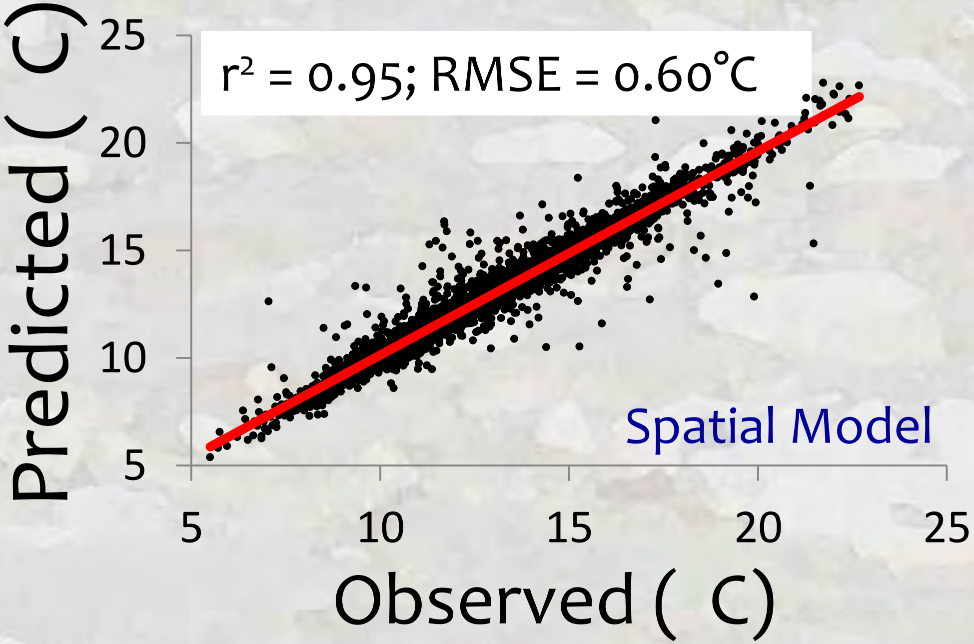
n = 4,487

<u>Covariate Predictors</u>

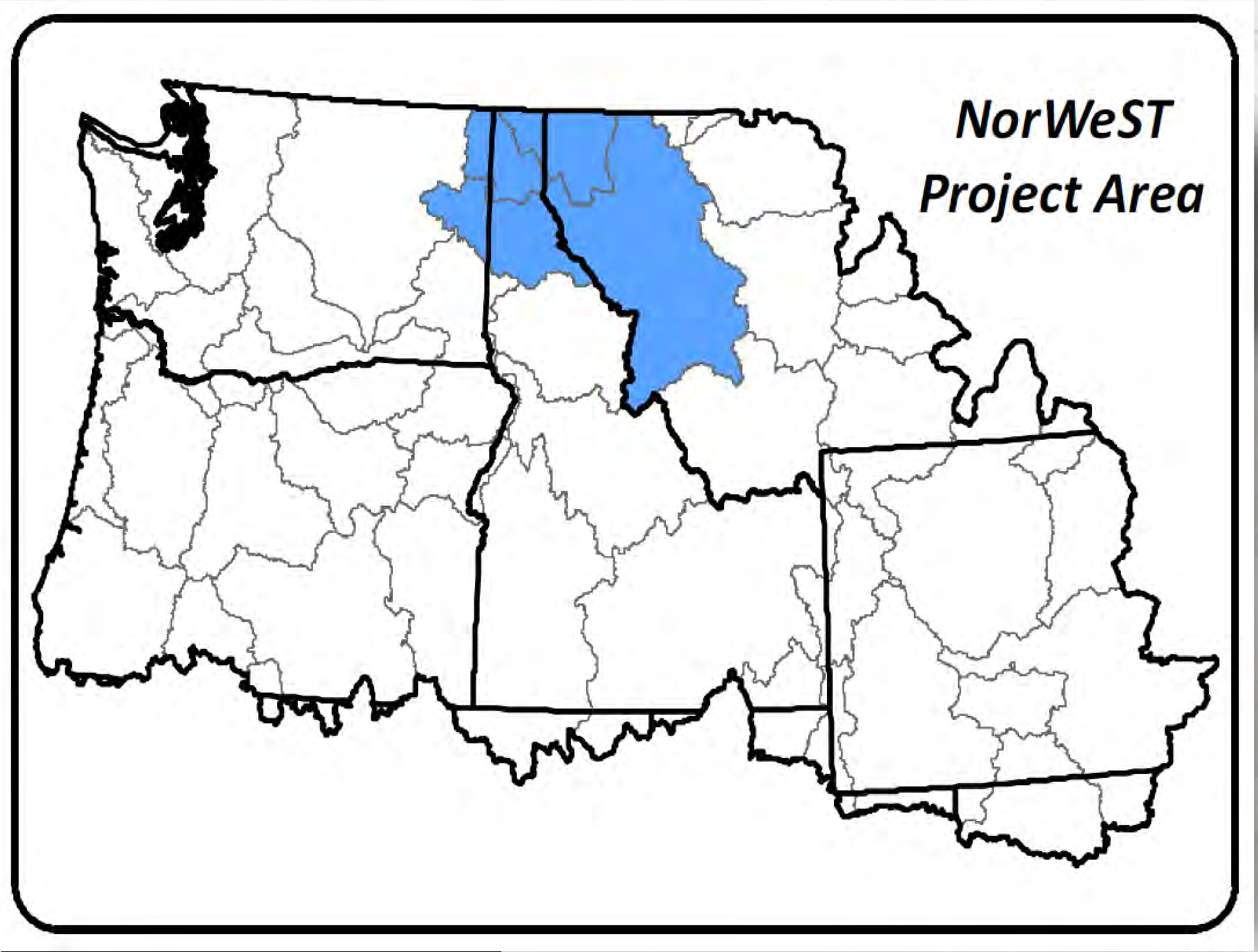
1. Elevation (m)
2. Canopy (%)
3. Stream slope (%)
4. Ave Precipitation (mm)
5. Latitude (km)
6. Lakes upstream (%)
7. Baseflow Index
8. Watershed size (km²)

9. Discharge (m³/s)
   USGS gage data
10. Air Temperature (°C)
   RegCM3 NCEP reanalysis
   Hostetler et al. 2011

Mean August Temperature

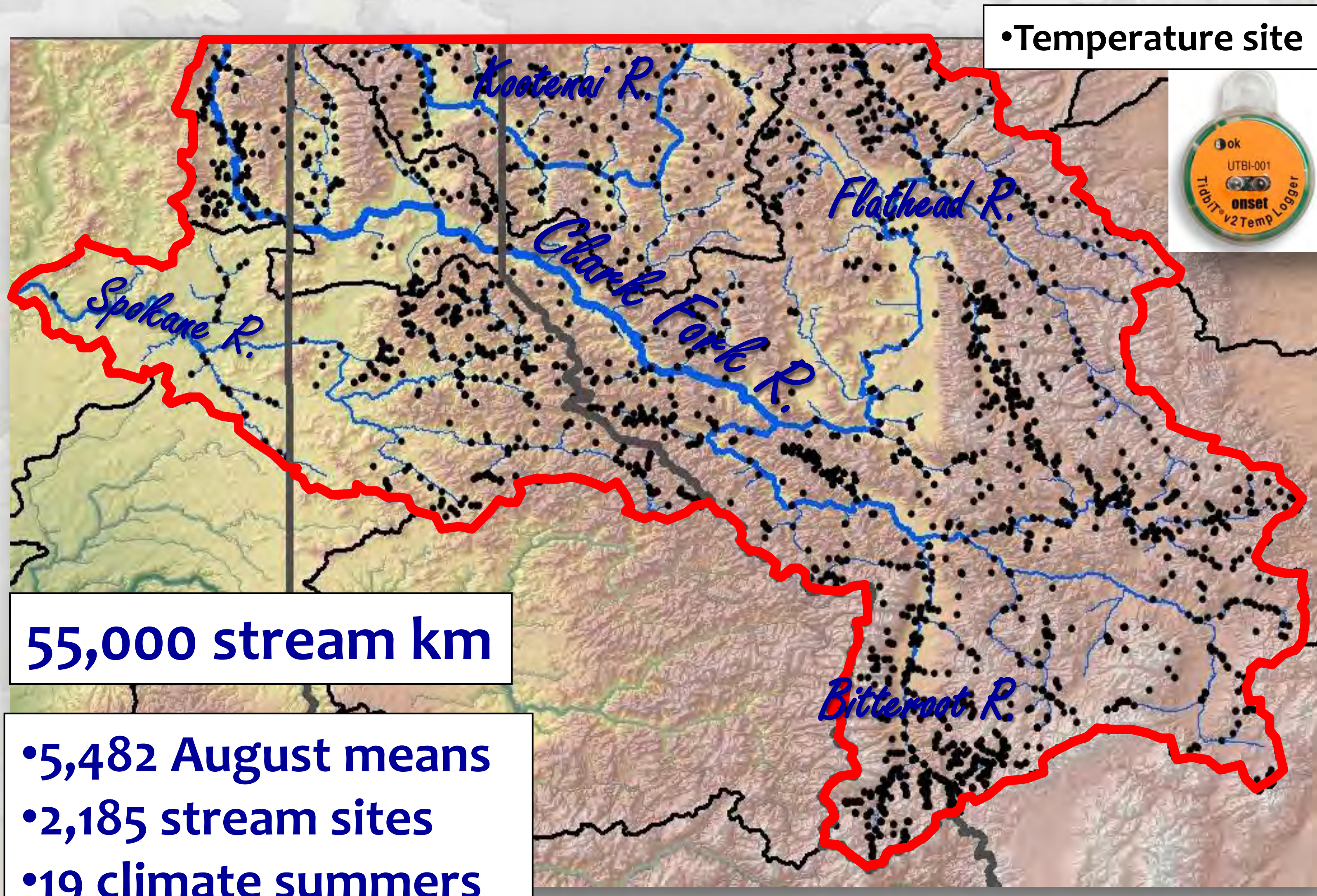


Example: SpoKoot River Basins



Example: SpoKoot River Basins

Data extracted from NorWeST



55,000 stream km

- 5,482 August means
- 2,185 stream sites
- 19 climate summers

SpoKoot River Temp Model

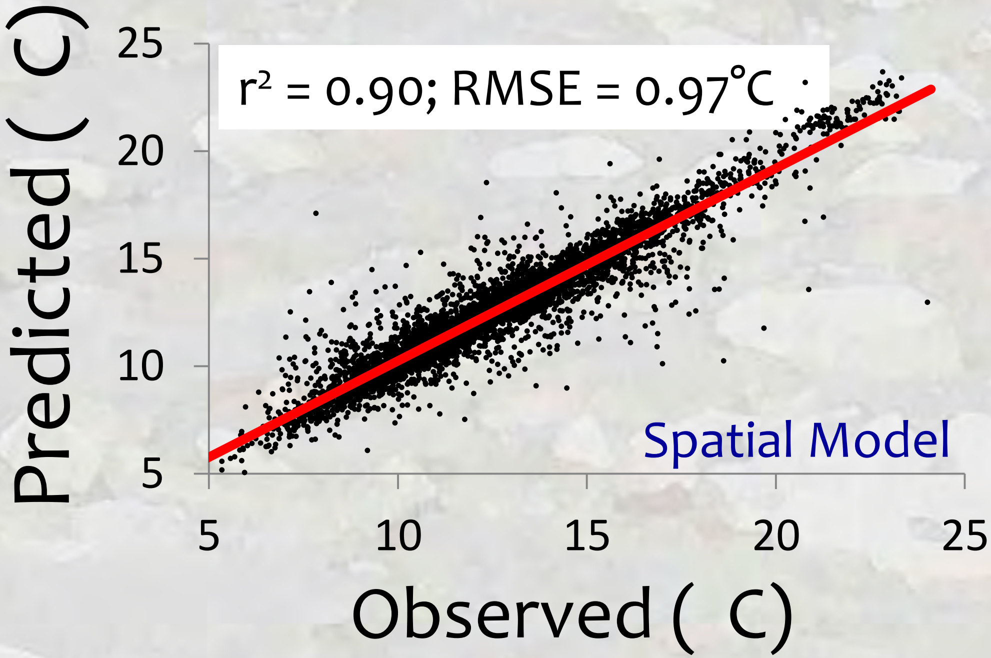
n = 5,482

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)

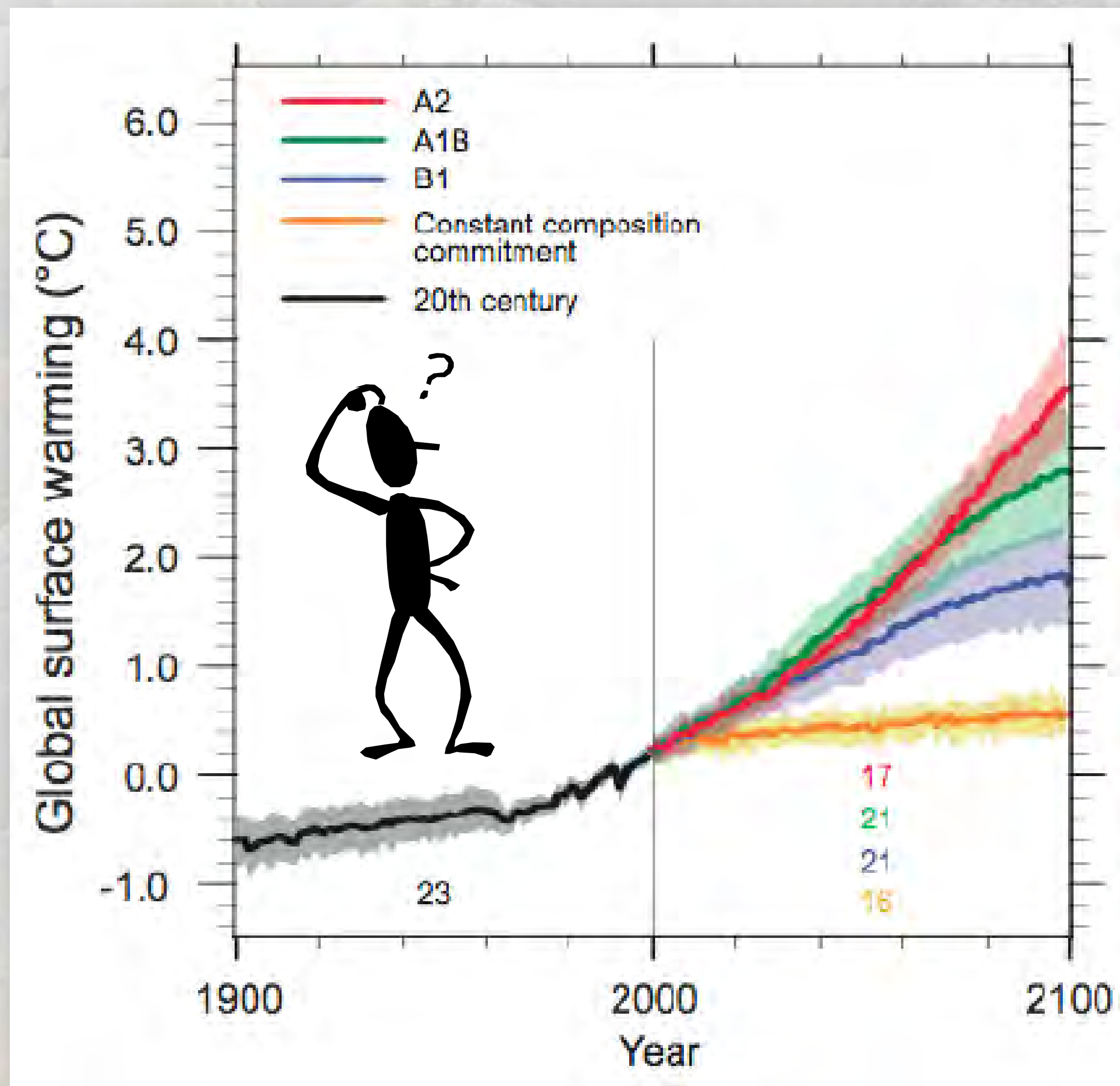
9. Discharge (m^3/s)
   USGS gage data
10. Air Temperature (°C)
    RegCM3 NCEP reanalysis
    Hostetler et al. 2011

Mean August Temperature



Models Enable Climate Scenario Maps

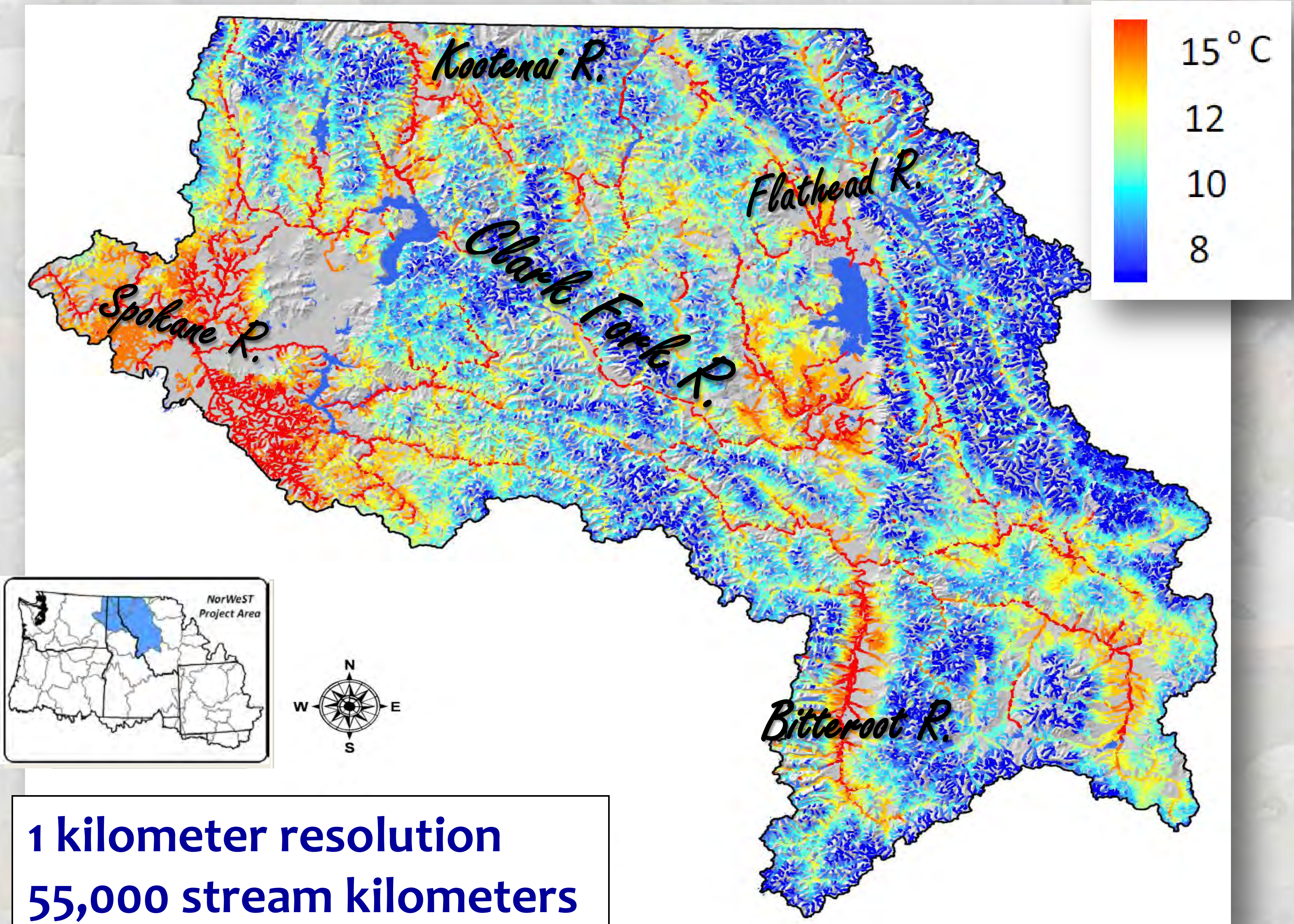
Many possibilities exist…



Adjust air & discharge values to represent scenarios

Historic Scenario: SpoKoot Unit (S1_93-11)

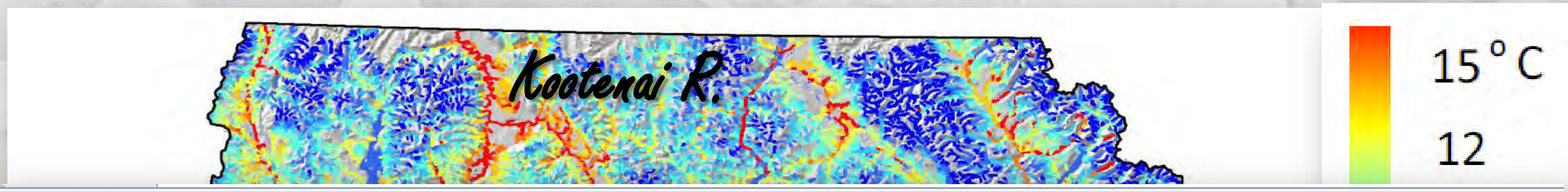
1993-2011 mean August stream temperatures



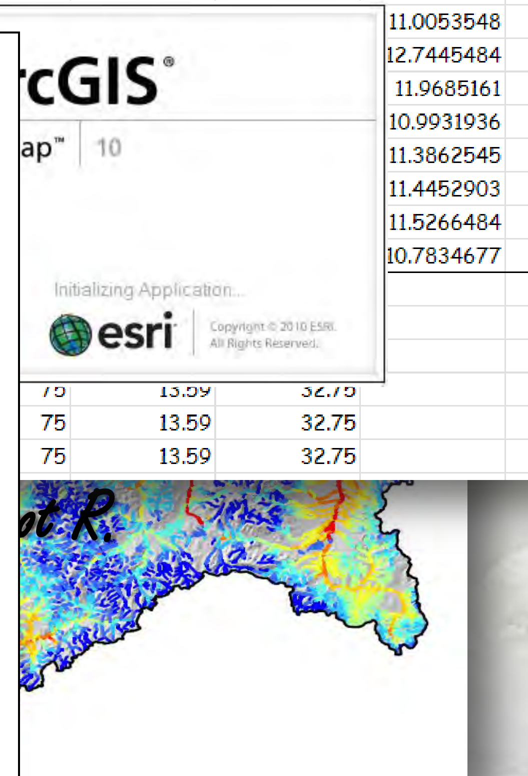
1 kilometer resolution
55,000 stream kilometers

Historic Scenario: SpoKoot Unit (S1_93-11)

1993-2011 mean August stream temperatures



CANOPY	SLOPE	PRECIP	CUMDRAINAG	Y_COORD	NLCD11PC	NLCD12PC	BFI	Air_August	Flow_August	Stream_August
2.82	0.08857	299.6256	19.833	1623663.32	0	0	79	14.02	35.71	12.0812903
2.82	0.08857	299.6256	19.833	1623663.32	0	0	79	13.20	40.52	12.333771
2.82	0.08857	299.6256	19.833	1623663.32	0	0	79	13.00	38.99	11.4041581
12.23	0.03514	242.42	69.271	1620504.73	0.012	0	80	15.84	18.47	12.2216452
12.23										11.0053548
										12.7445484
										11.9685161
										10.9931936
										11.3862545
										11.4452903
										11.5266484
										10.7834677
							75	13.59	32.75	
							75	13.59	32.75	
							75	13.59	32.75	



R1 Forests Completed…

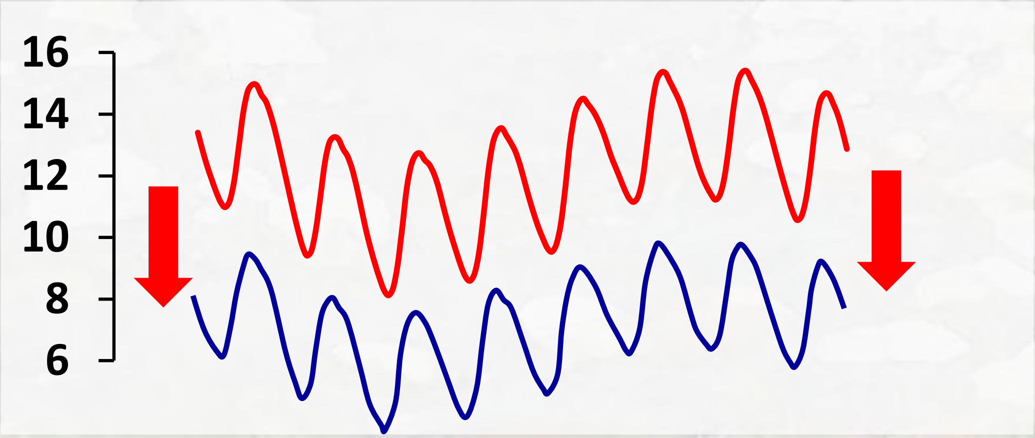
- Nez Perce NF
- Bitterroot NF
- Clearwater NF
- Panhandle NF
- Lolo NF
- Kootenai NF
- Flathead NF
- Helena NF
- Deerlodge NF

Scenarios coming for ~40 additional forests in R1, 2, 4, and 6

Application: Quantify Thermal Degradation

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

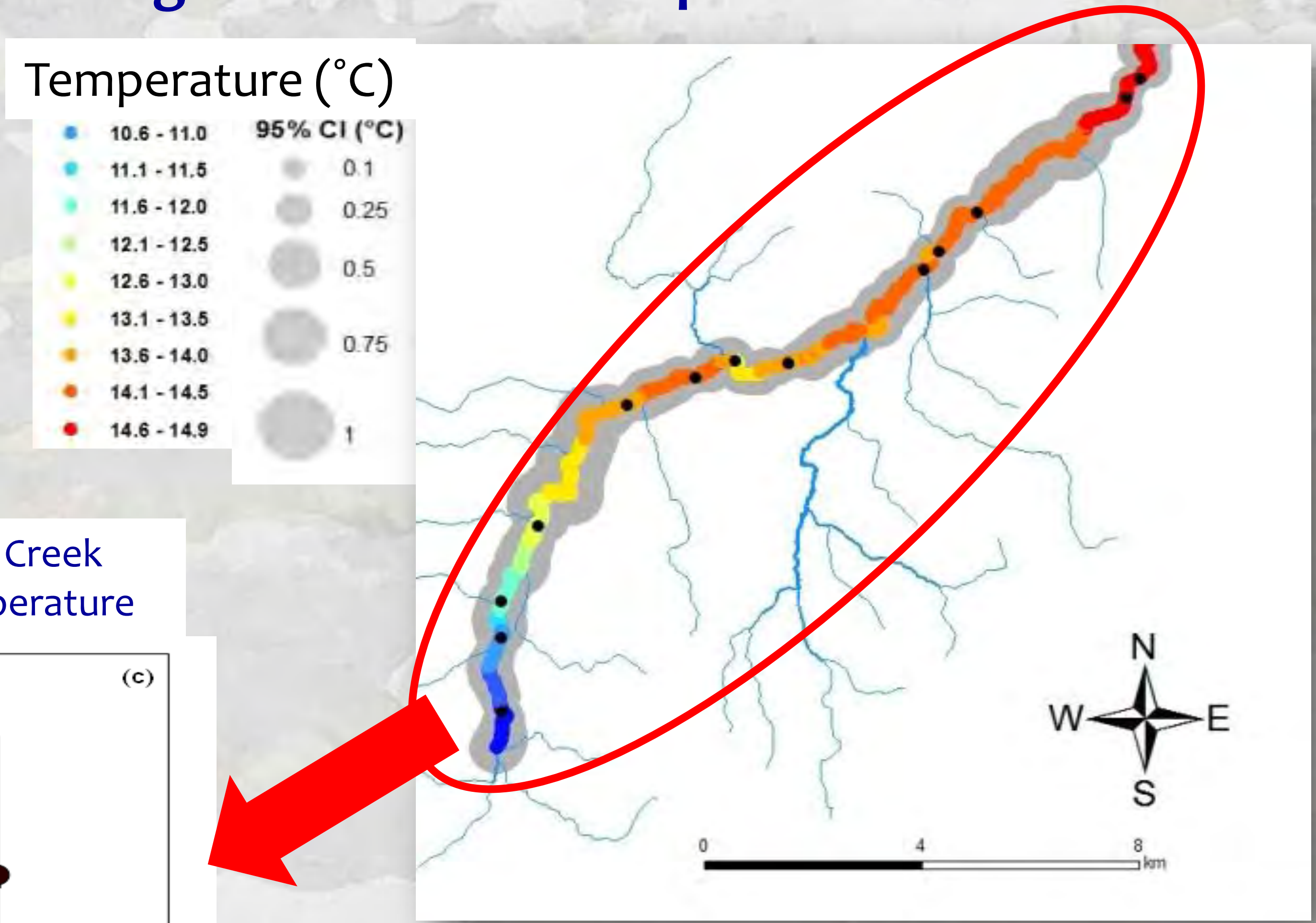
"How much cooler could we make this stream?"

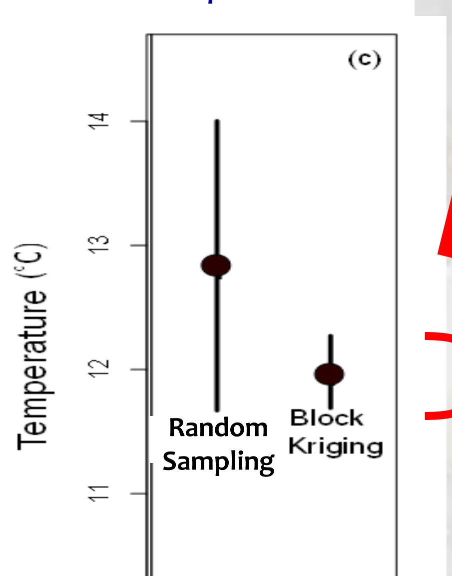


1) Pick "degraded" and "healthy" streams to compare

Application: Quantify Thermal Degradation

2) Block-krige estimates of temperature at desired scale

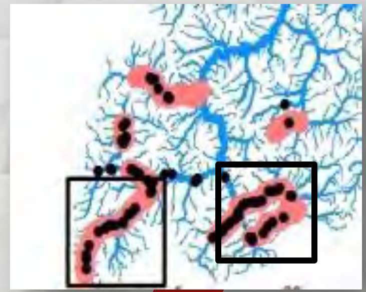


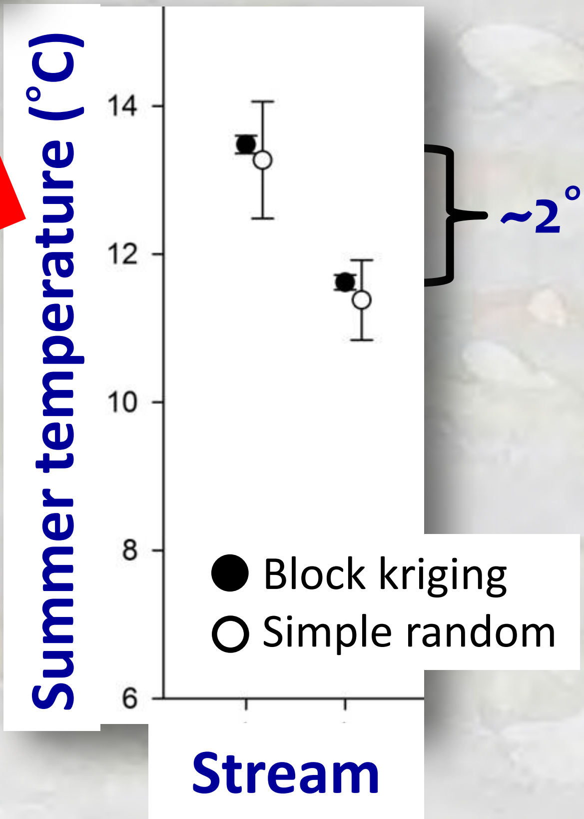


Precise & unbiased estimates

Application: Quantify Thermal Degradation

3) Compare estimates among streams



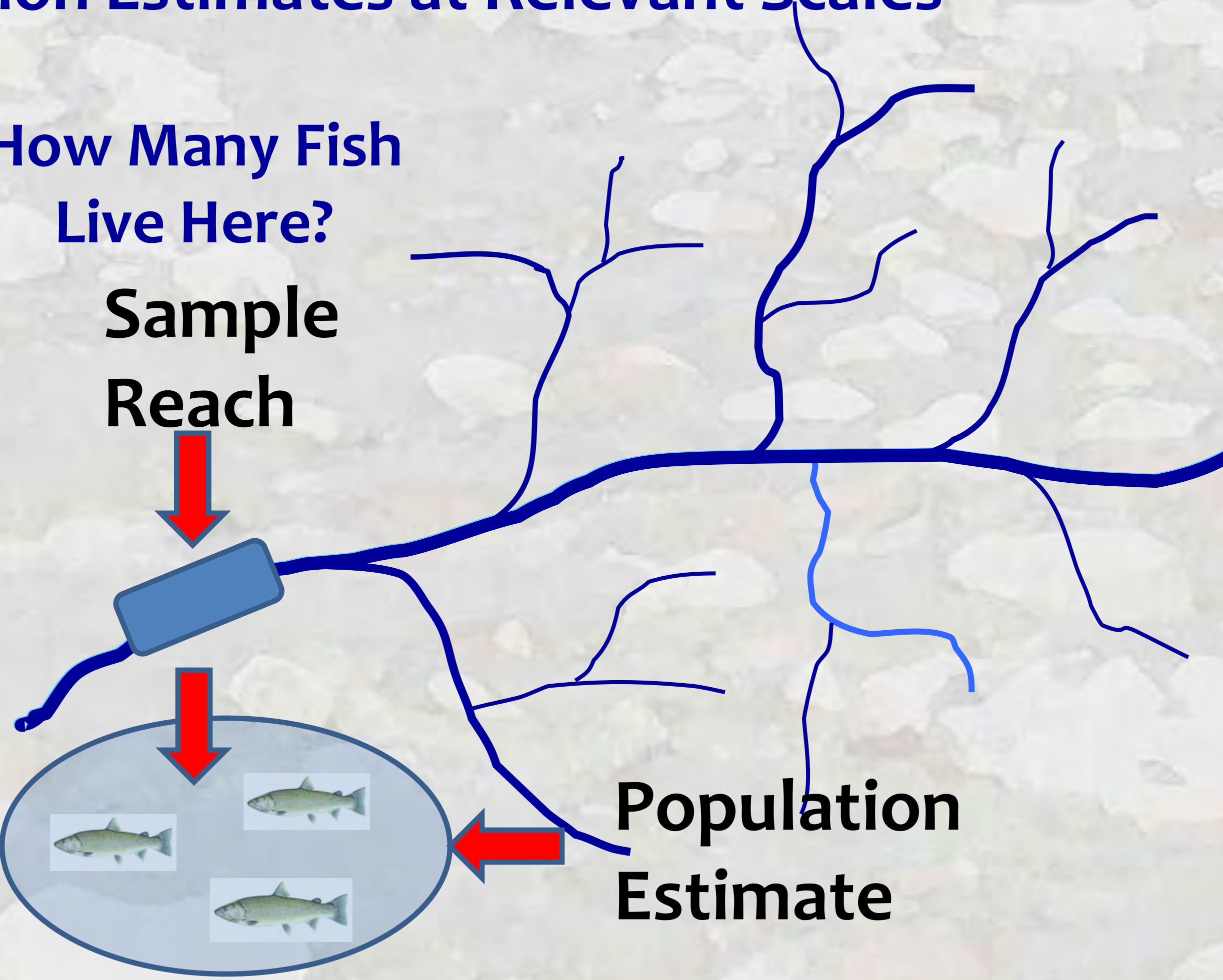


~2°C cooling is possible

Block-Kriging of Fish Populations

Population Estimates at Relevant Scales

How Many Fish Live Here?

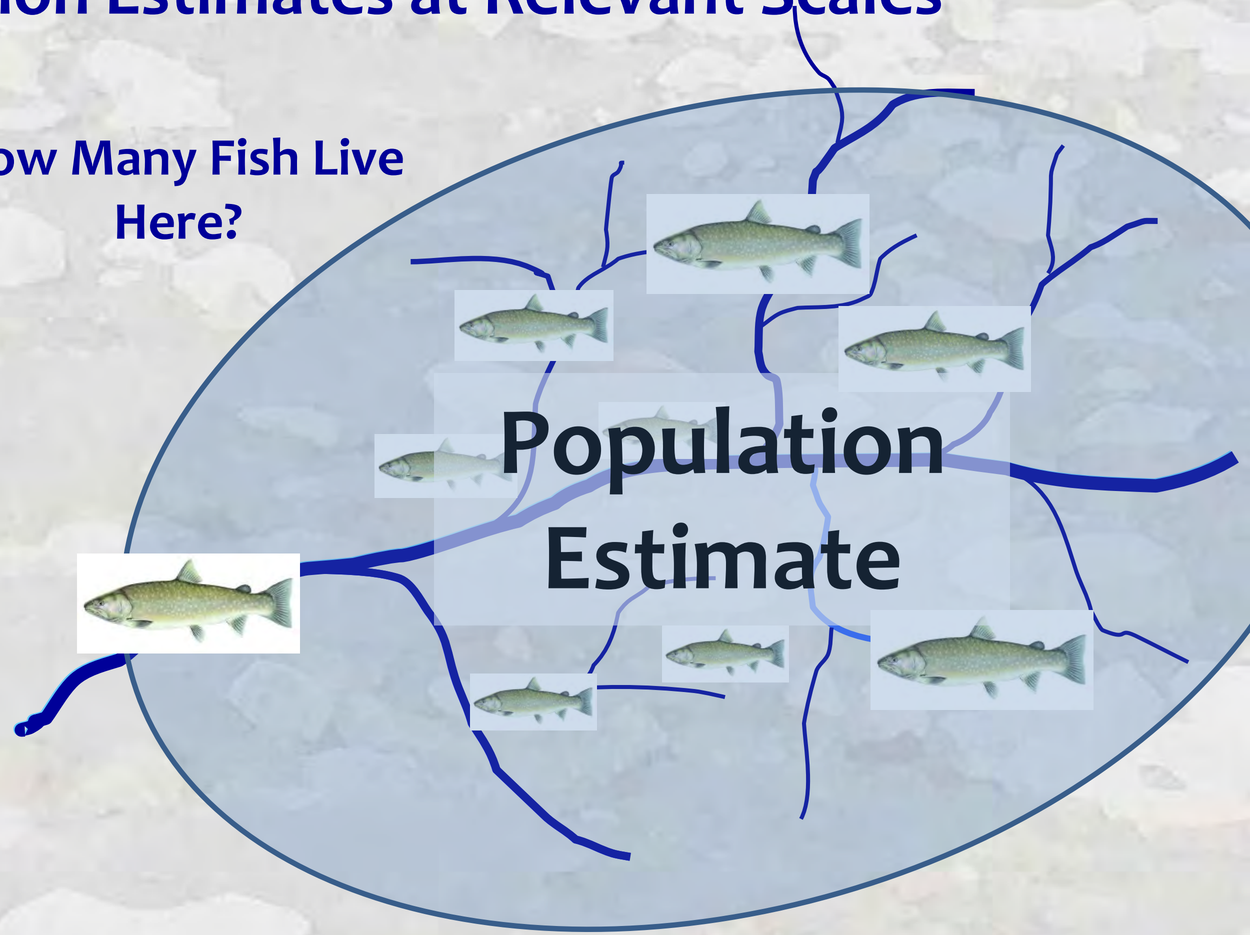


Traditional Estimation Scale = Reach (10’s – 100’s meters)

Block-Kriging of Fish Populations

Population Estimates at Relevant Scales

How Many Fish Live Here?



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

Block-Kriging of Fish Populations

Population Estimates at Relevant Scales

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

Estimate

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

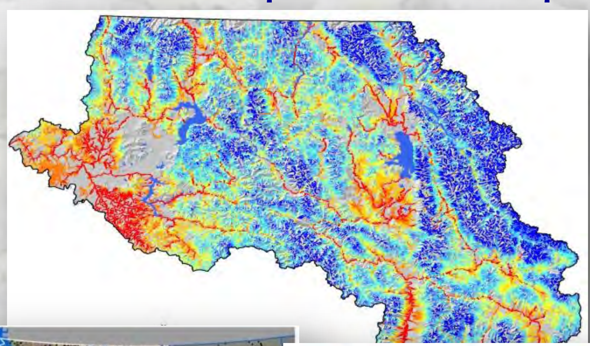
Sampling and geostatistics for spatial data[1]

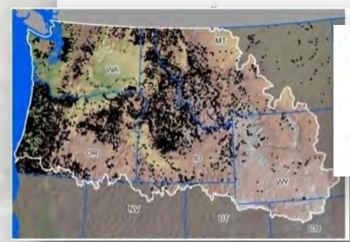
Jay VER HOEF, Alaska Department of Fish and Game, 1300 College Road, Fairbanks, Alaska 99701, U.S.A., e-mail: jay_ver_hoef@fishgame.state.ak.us

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

Develop Accurate & Consistent Thermal Criteria

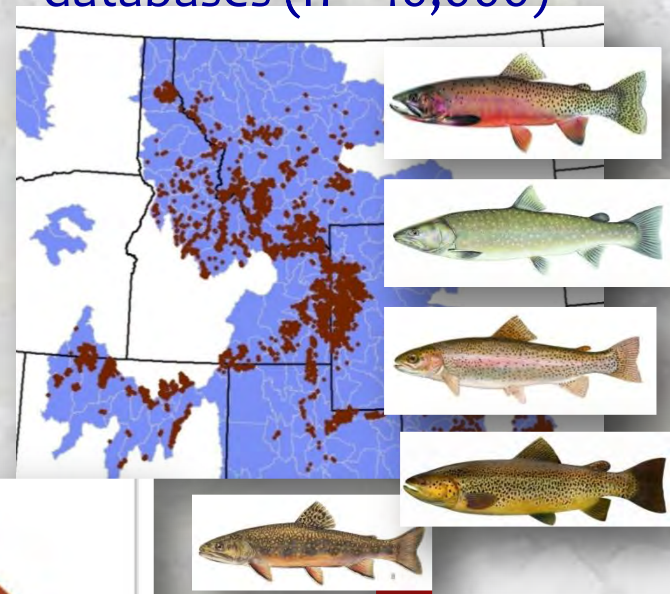
Stream temperature maps

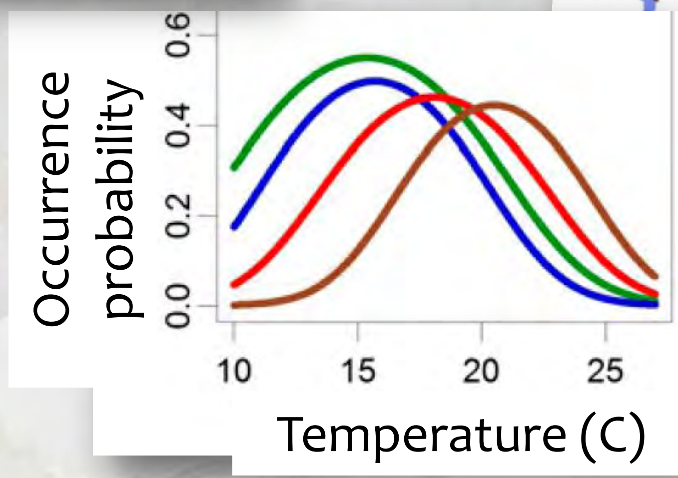




NorWeST Stream Temp

Regional fish survey databases (n = 10,000)



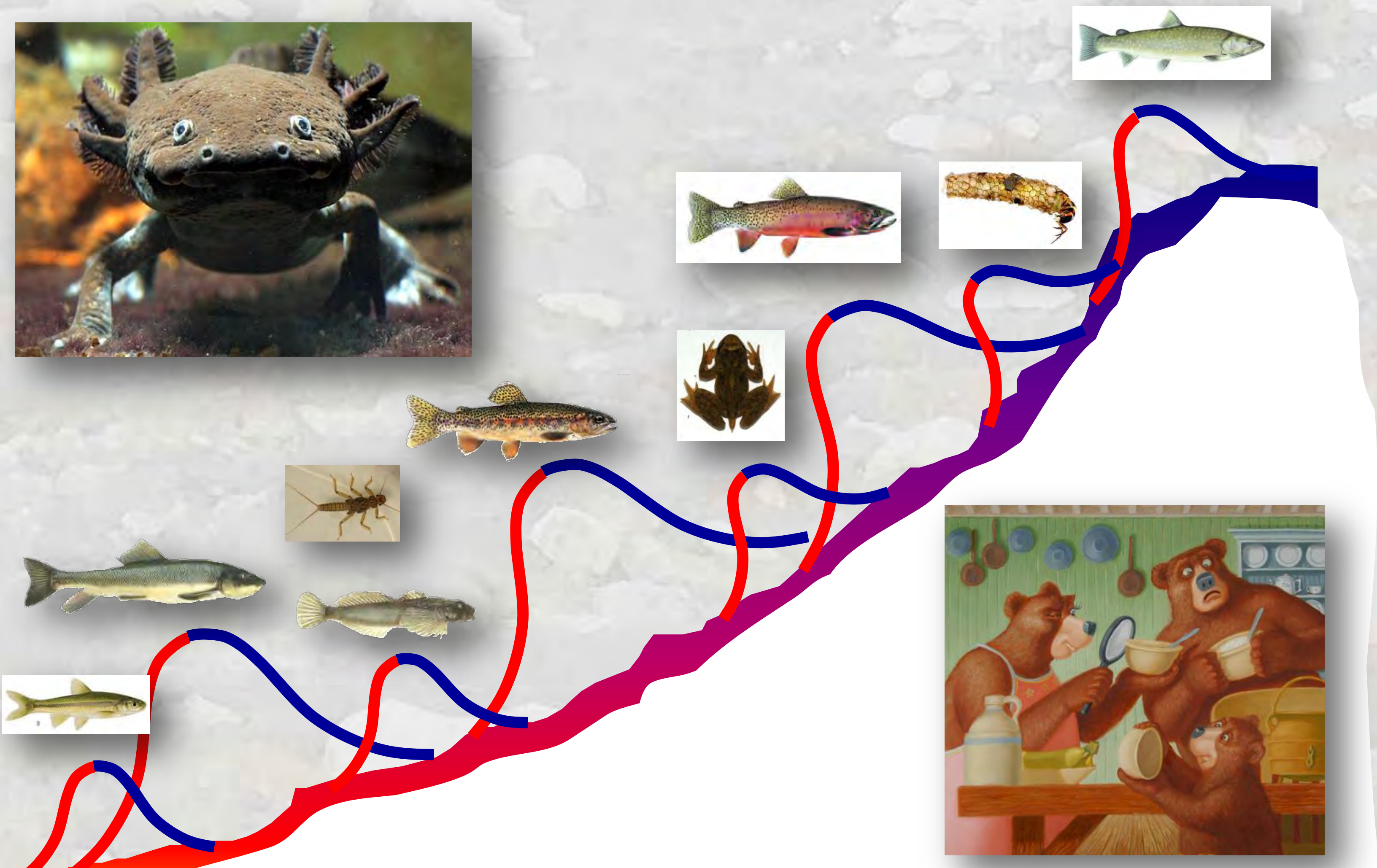


Wenger et al. 2011a. *PNAS* **108:**14175-14180

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

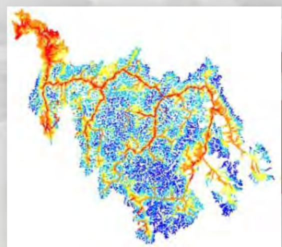
Thermal Niches For All Stream Critters

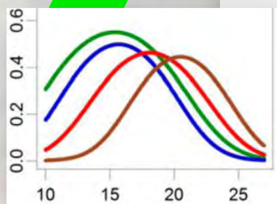
Just need georeferenced biological survey data

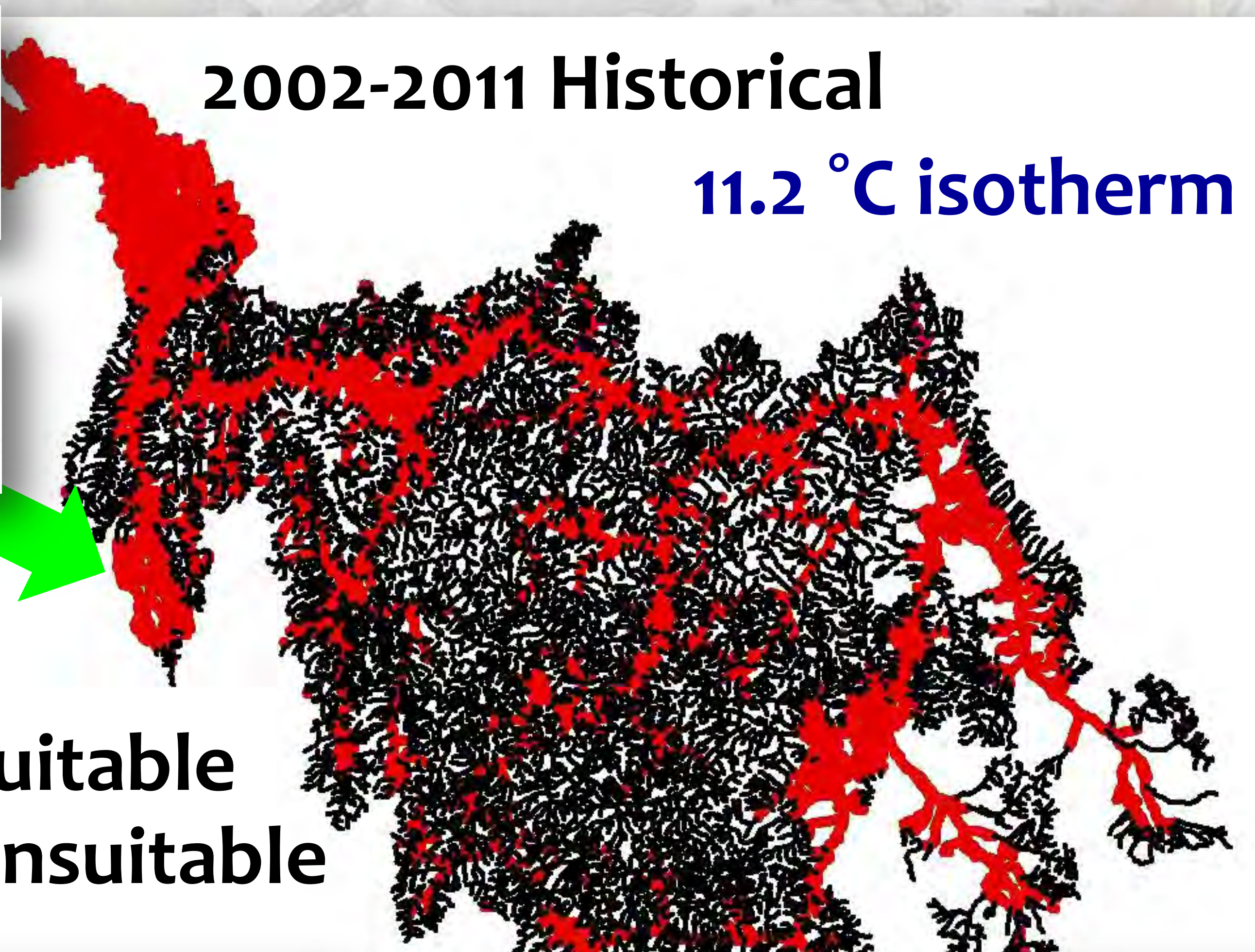


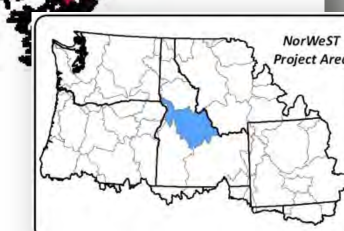
Too warm…Too cold…Just right

Salmon River Bull Trout Habitats

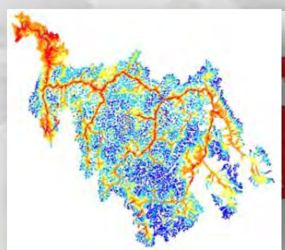


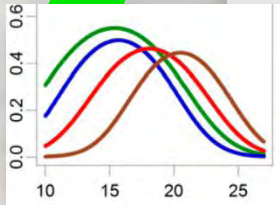


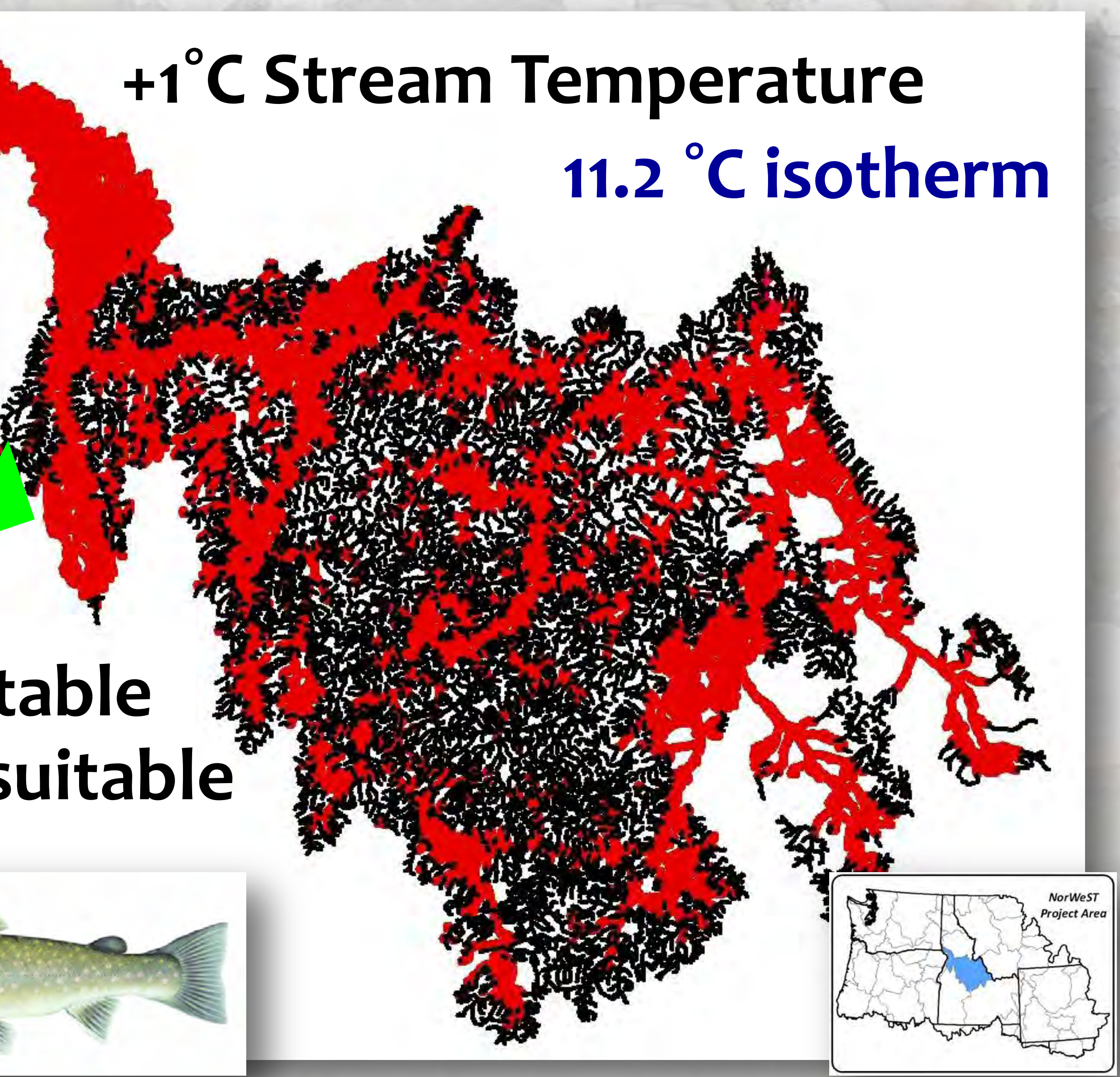




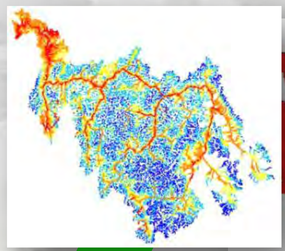
Salmon River Bull Trout Habitats

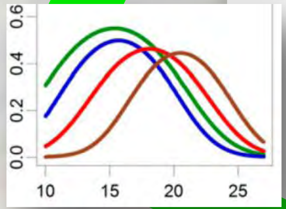


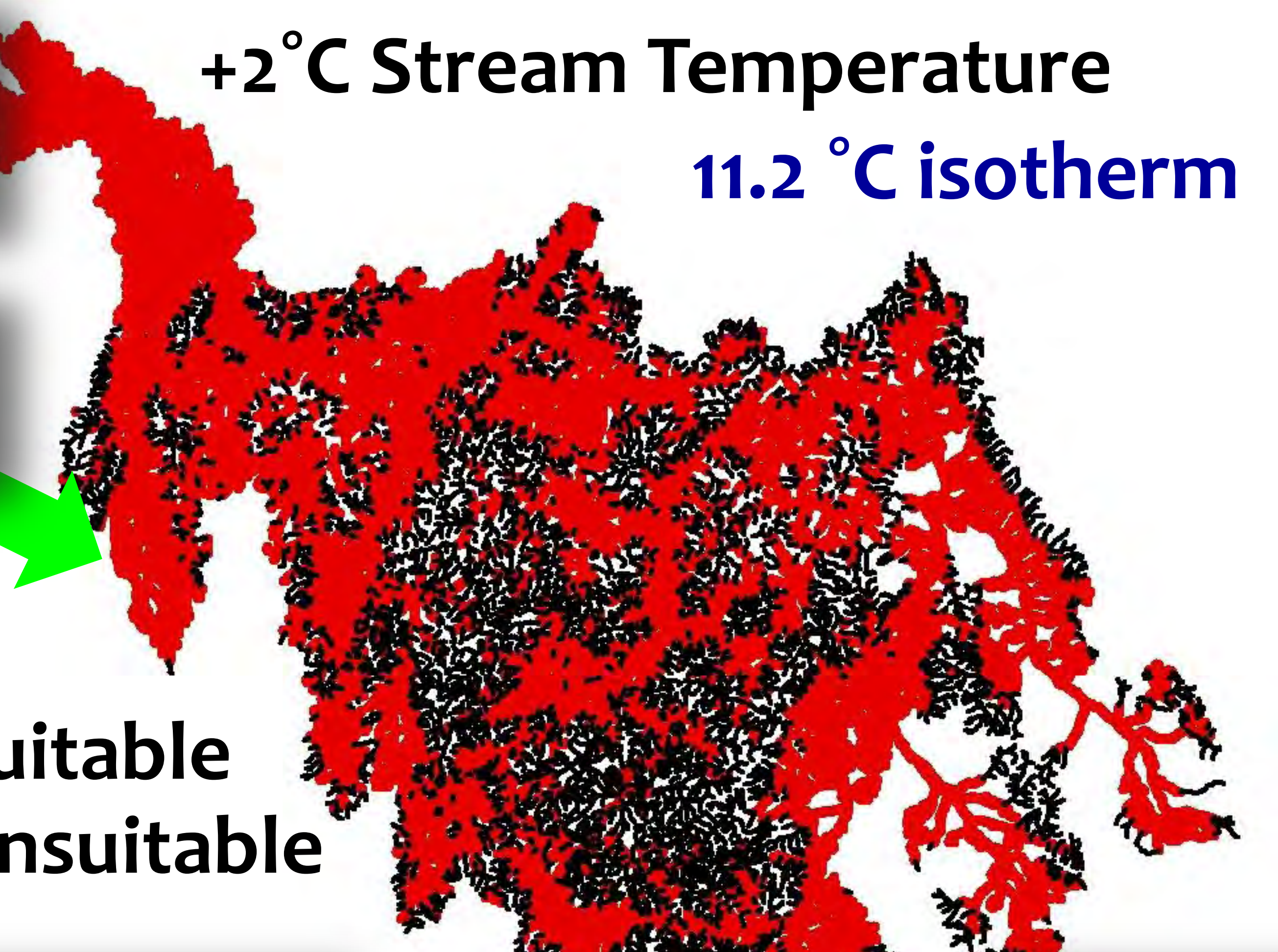


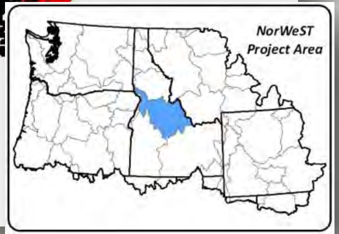


Salmon River Bull Trout Habitats



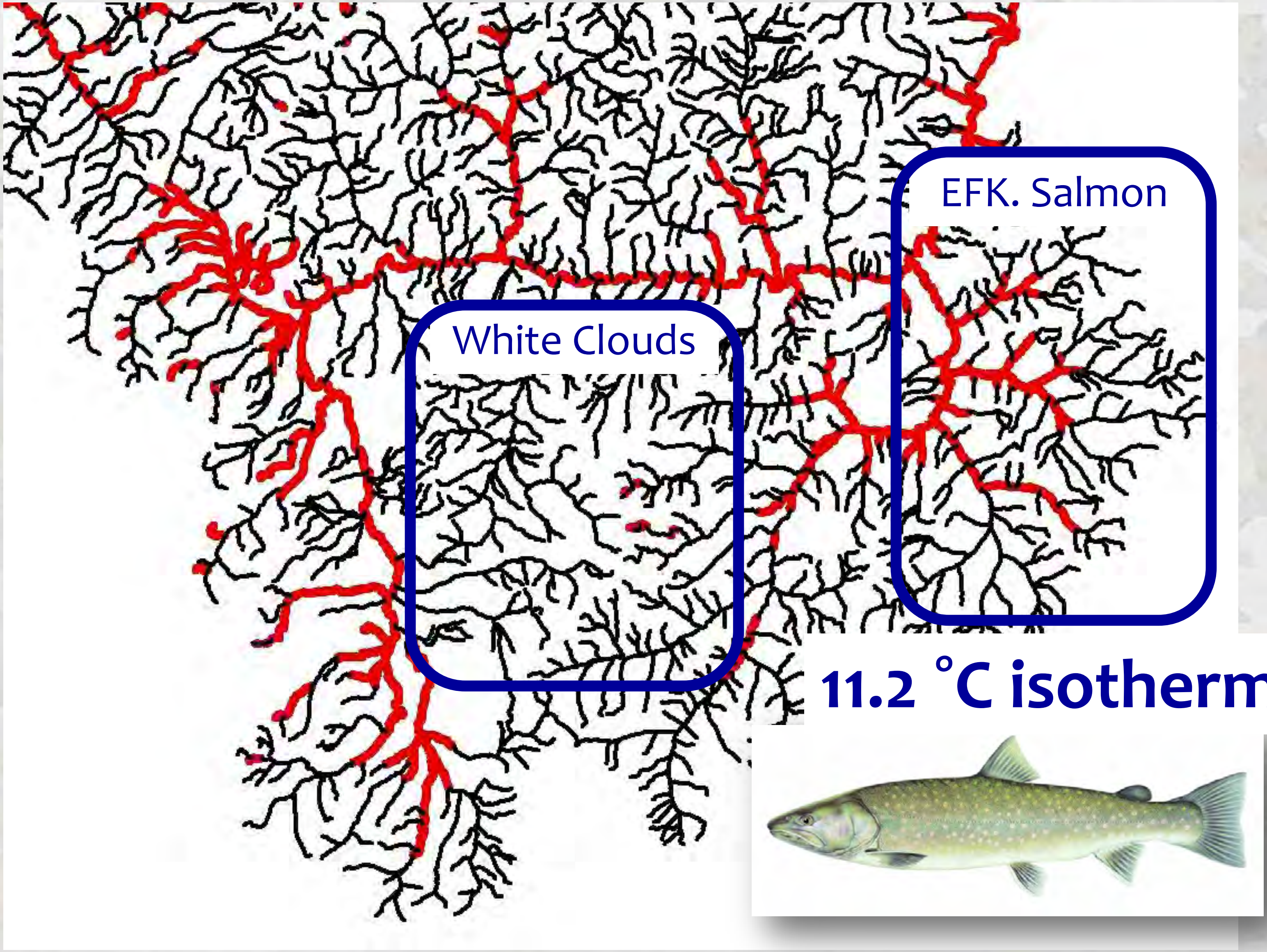






Spatial Variation in Habitat Loss

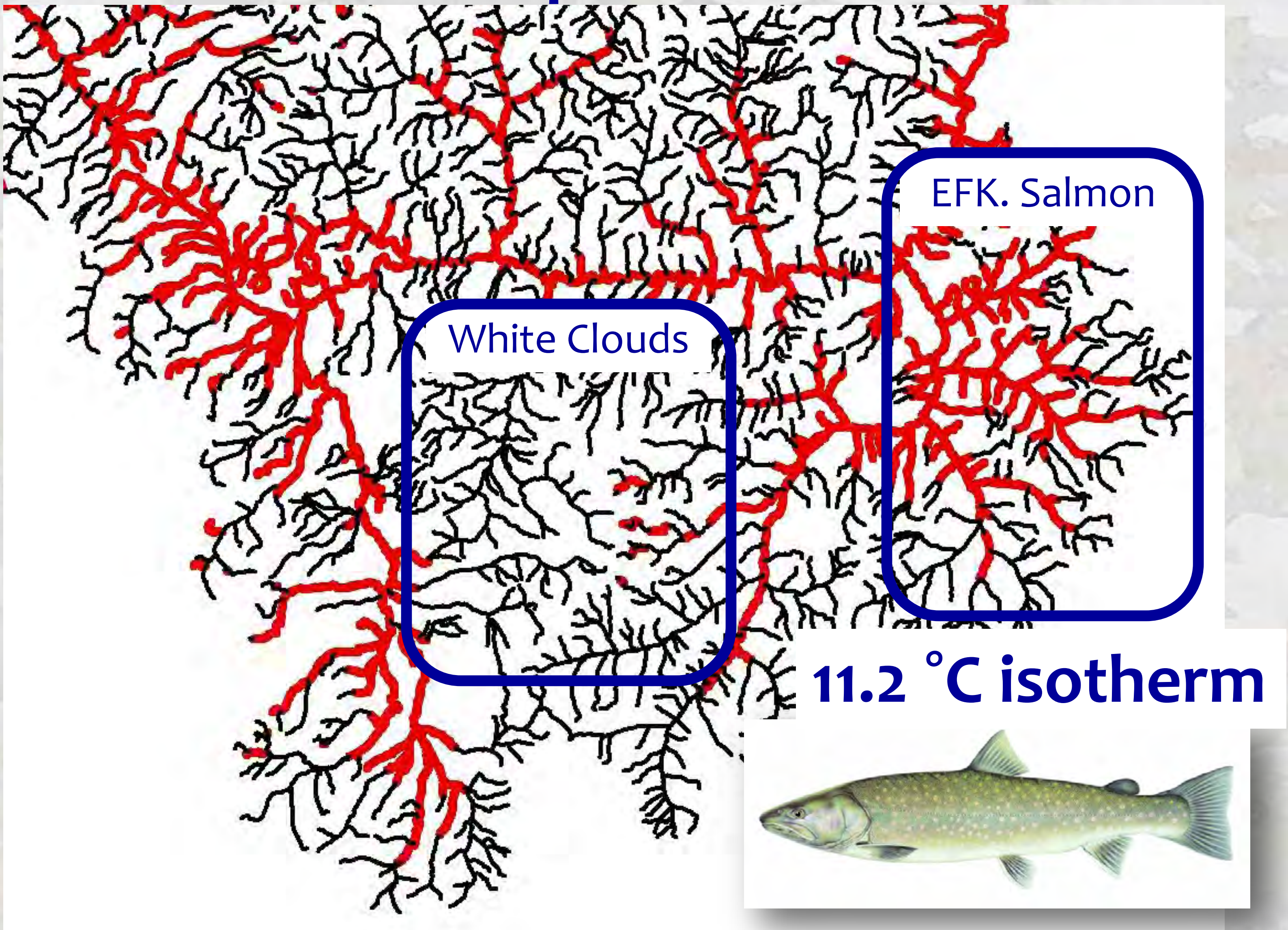
2002-2011 historical scenario



11.2 °C isotherm

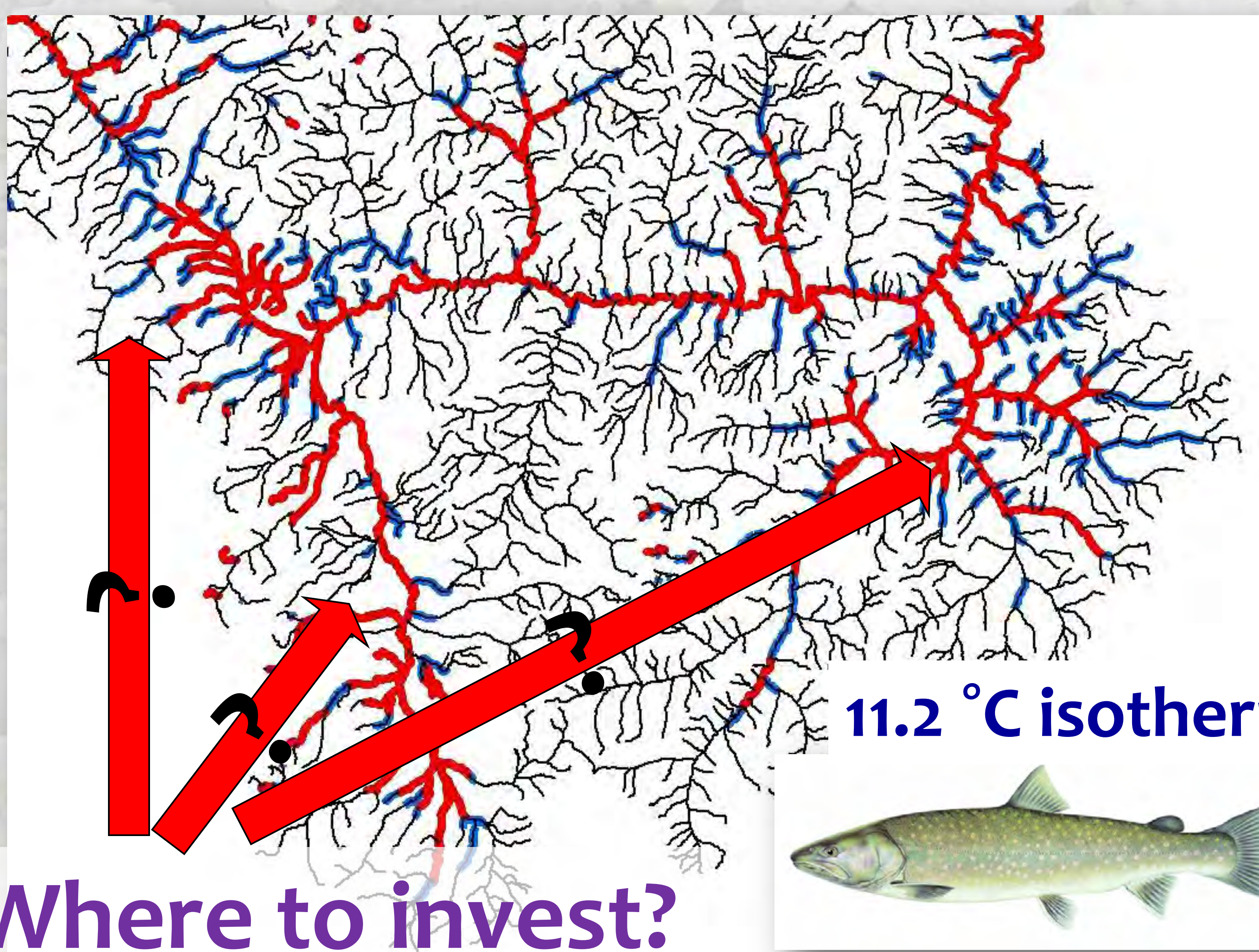
Spatial Variation in Habitat Loss

+1°C stream temperature scenario



Difference Map Shows Vulnerable Habitats

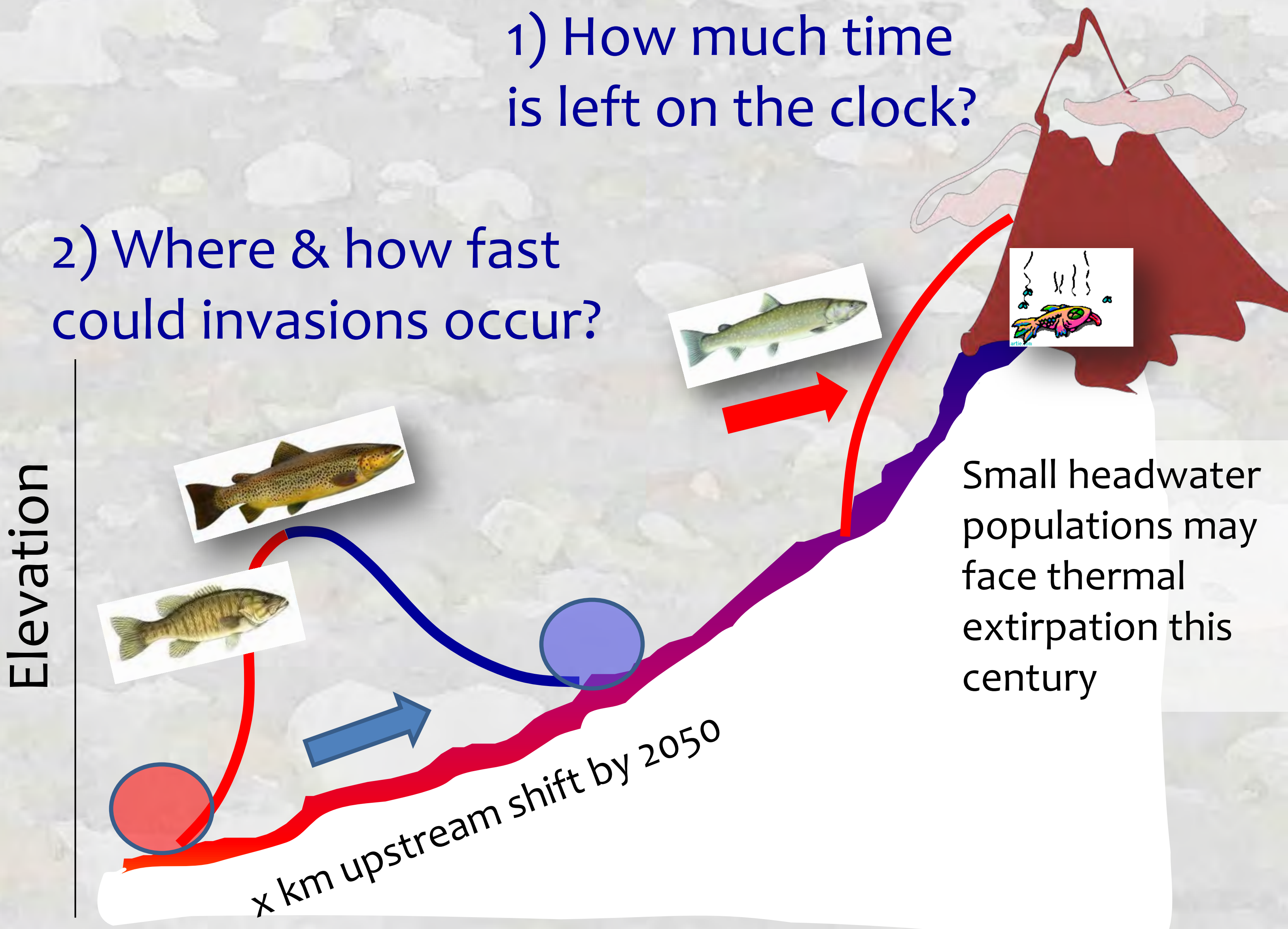
+1°C stream temperature scenario



Where to invest?

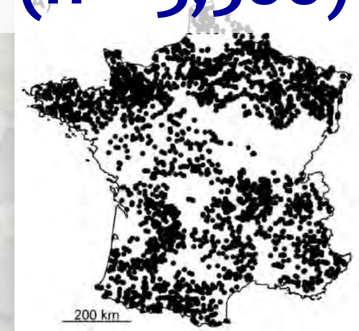
11.2 °C isotherm

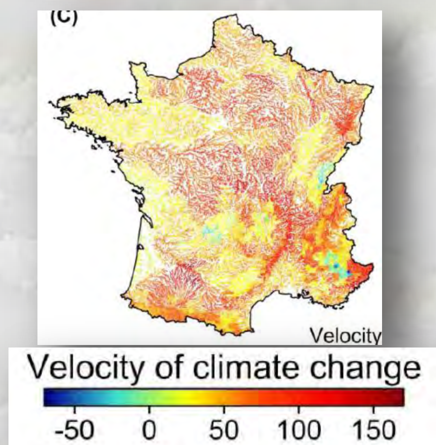
Precise Information Regarding Potential Species Invasions & Population Extirpations



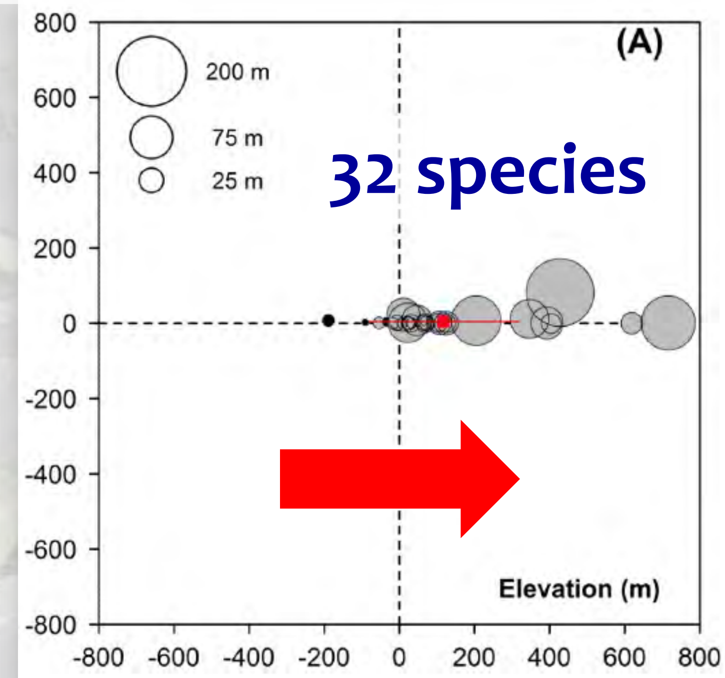
Climate is Causing Stream Fish Distributions to Shift…

Fish surveys (n = 3,500)





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



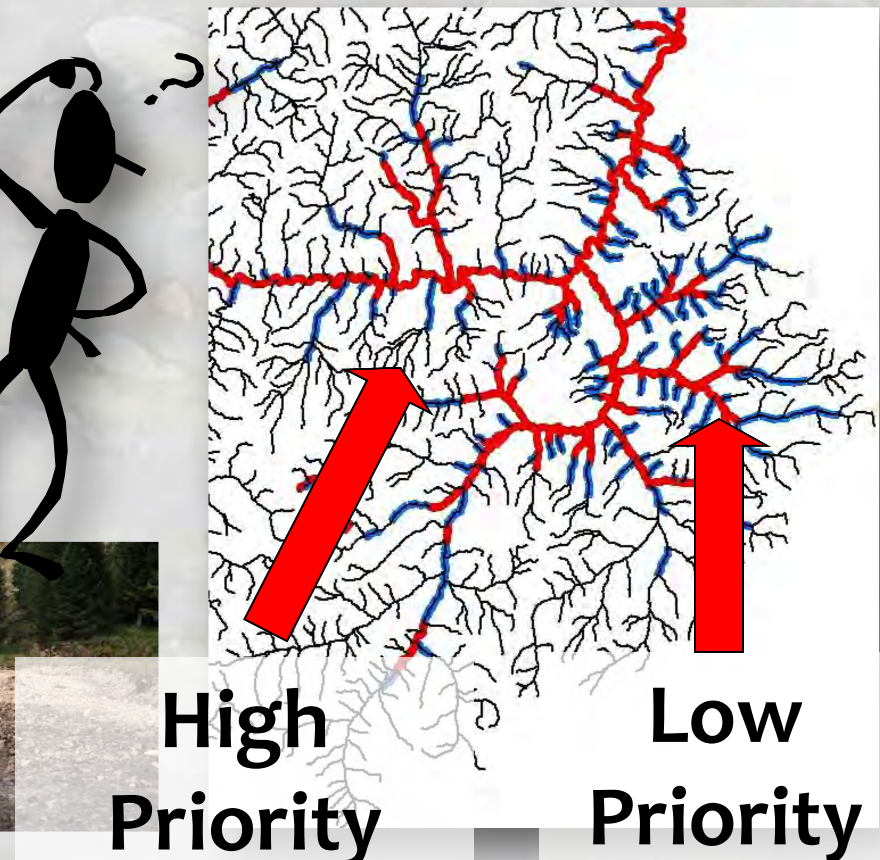
Change in Elevation (m)

…but shifts are slower than Climate Velocity

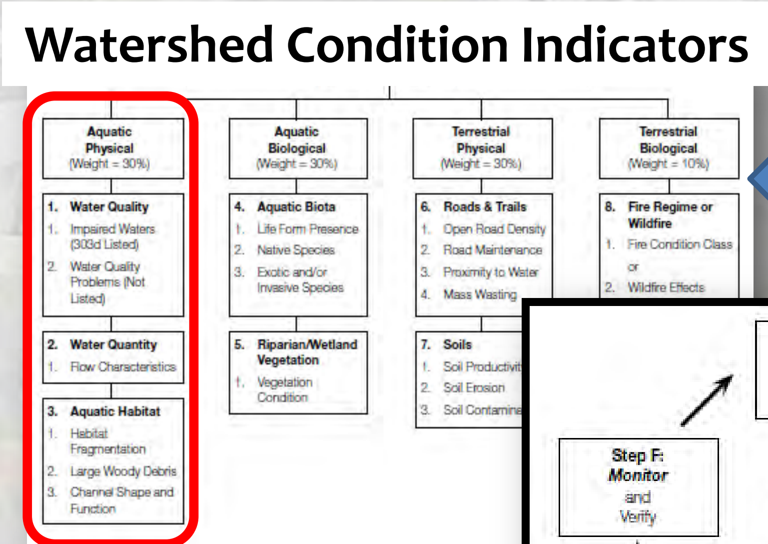
Comte & Grenouillet. 2013. Do stream fish track climate change? Assessing distibution shifts in recent decades. *Ecography*.

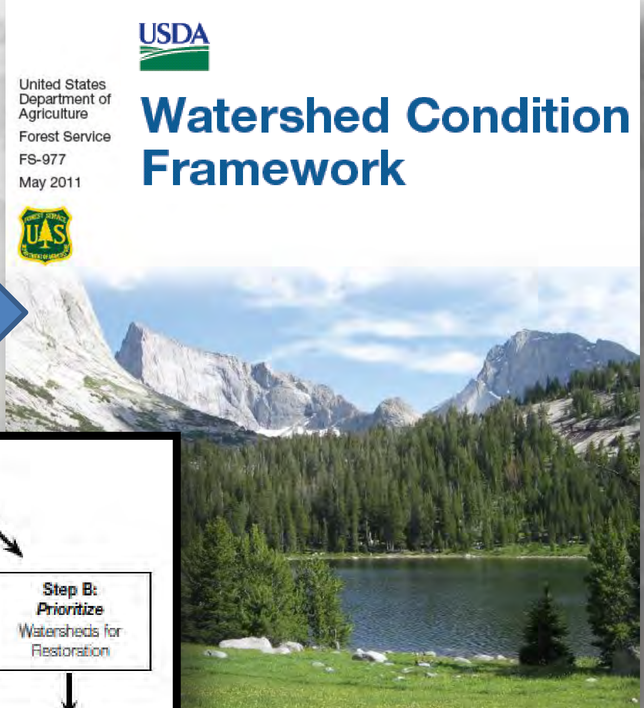
Strategic Prioritization of Restoration Actions is Possible

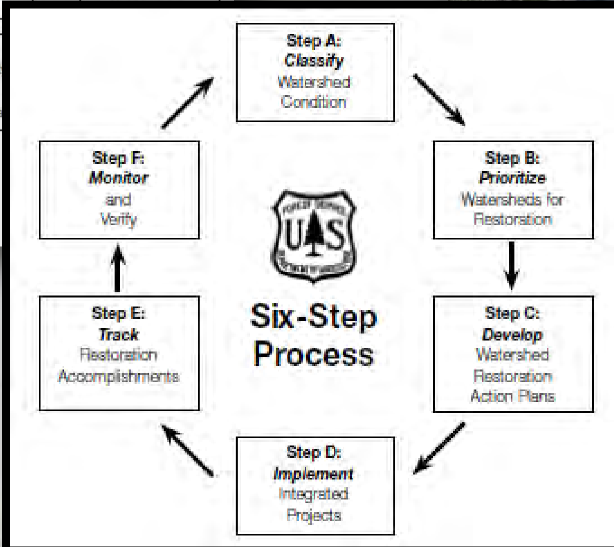
- Maintaining/restoring flow…
- Maintaining/restoring riparian…
- Restoring channel form/function…
- Prescribed burns limit wildfire risks…
- Non-native species control…
- Improve/impede fish passage…



Integrate with…

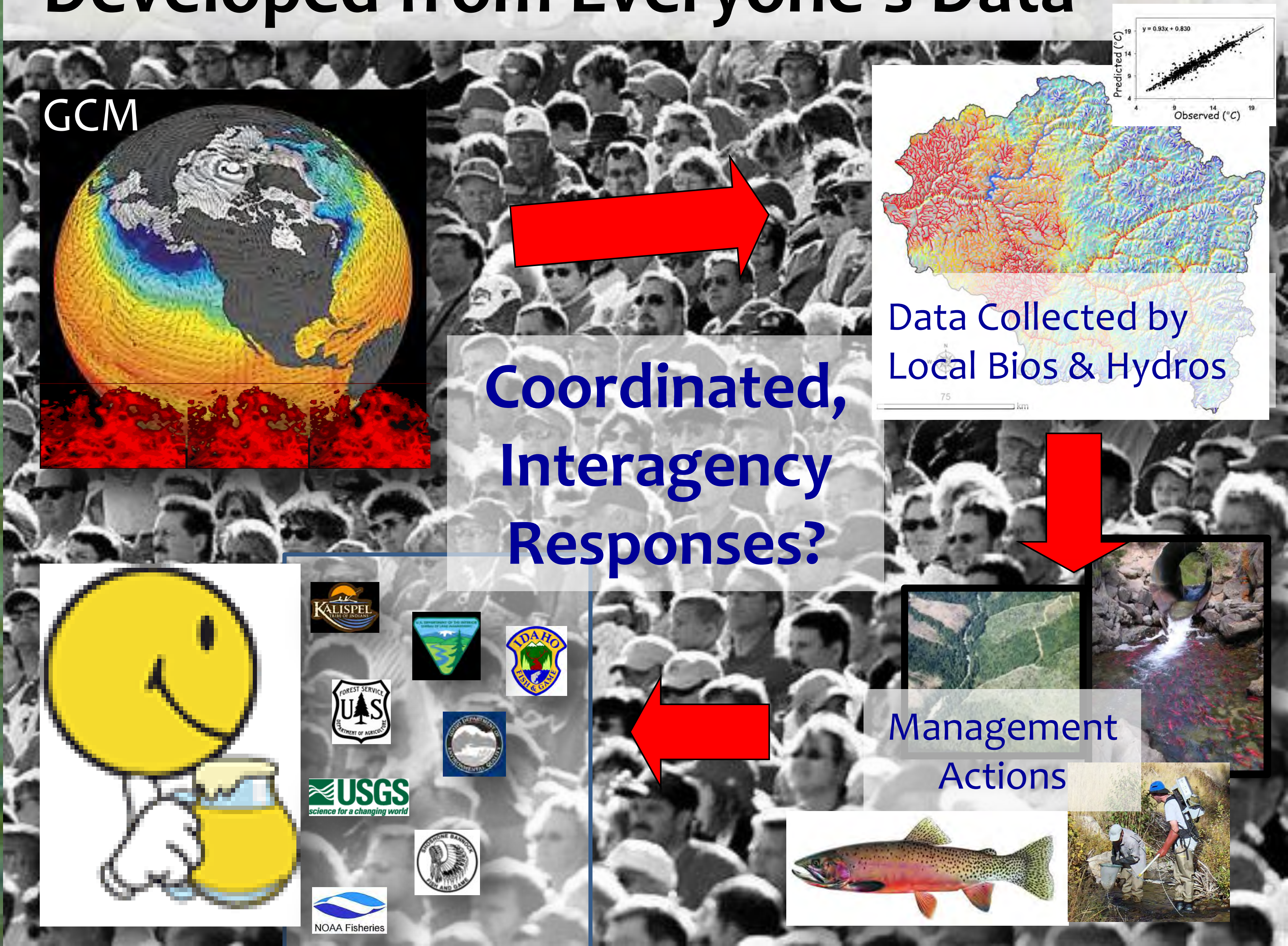






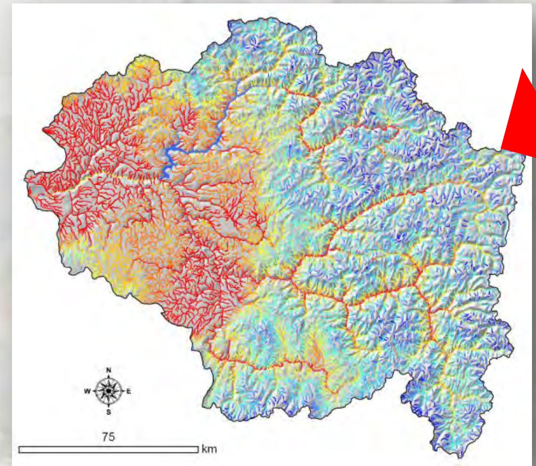
Forest Plan Revisions

NorWeST is a "Crowd-Sourced" Model Developed from Everyone's Data

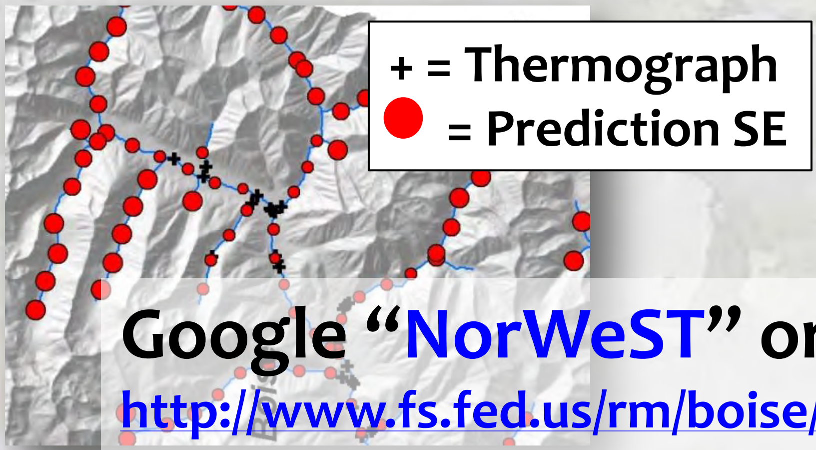


NorWeST Website Distributes Temperature Data as GIS Layers

1) GIS shapefiles of stream temperature scenarios



2) GIS shapefiles of stream temperature model prediction precision



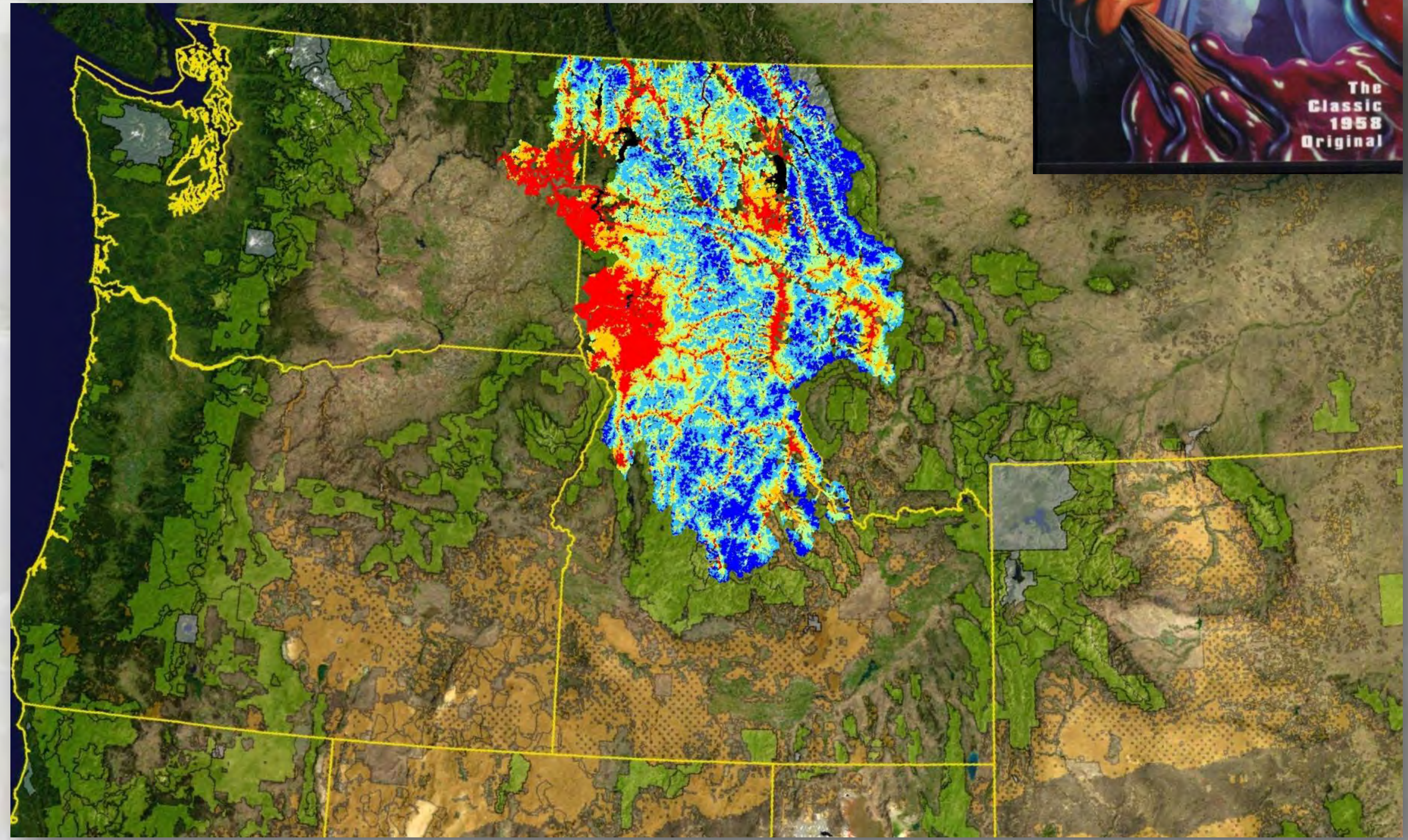
3) Temperature data summaries

Google "NorWeST" or go here…

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

NorWeST Blob Growing…

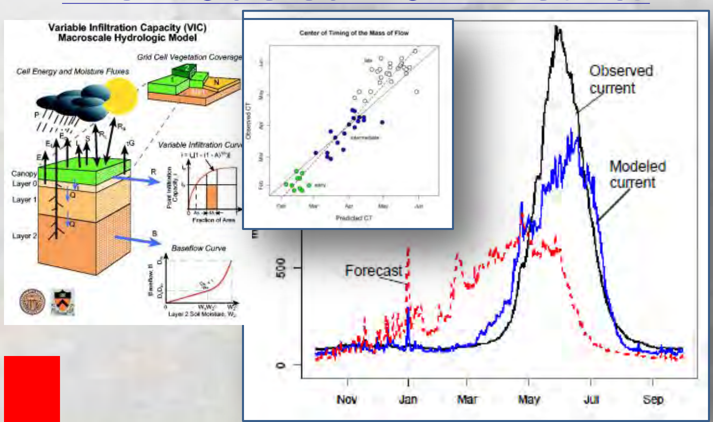
- 14,370 summers of data swallowed
- 92,000 stream kilometers of thermal ooze mapped



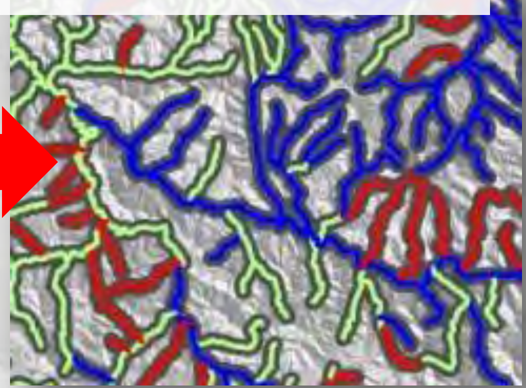
VIC Streamflow Scenarios – Western US

C. Luce expanding VIC nationally

VIC Modeled Flow Metrics



NHD+ stream segments
& climate scenarios

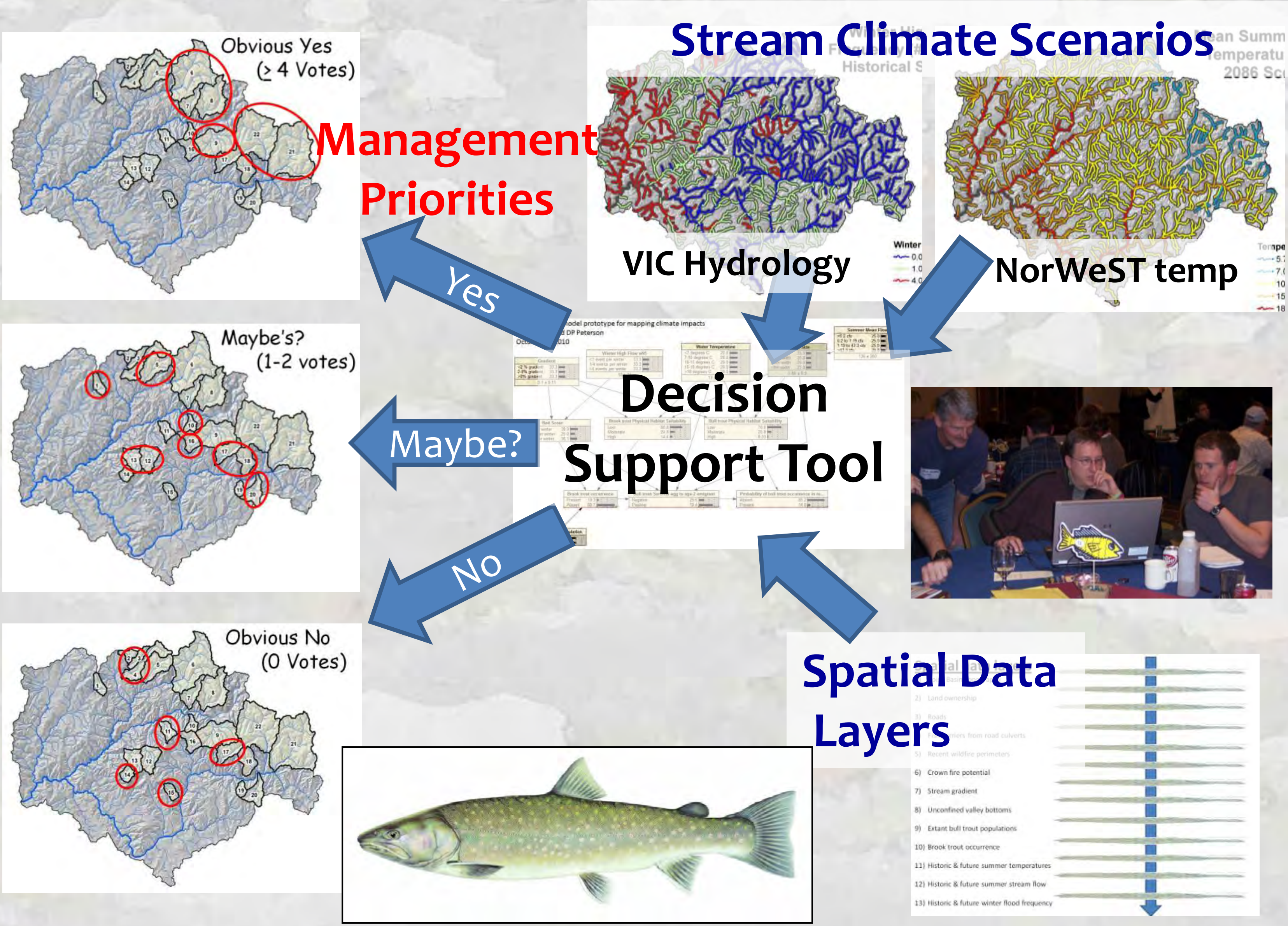


… for the western U.S.

Website:
http://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml

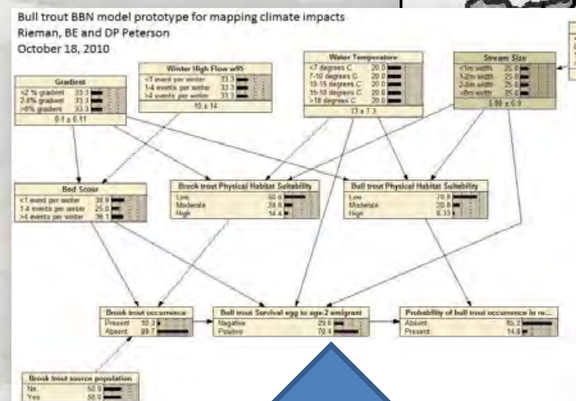
Wenger et al. 2010. *Water Resources Research* 46, W09513

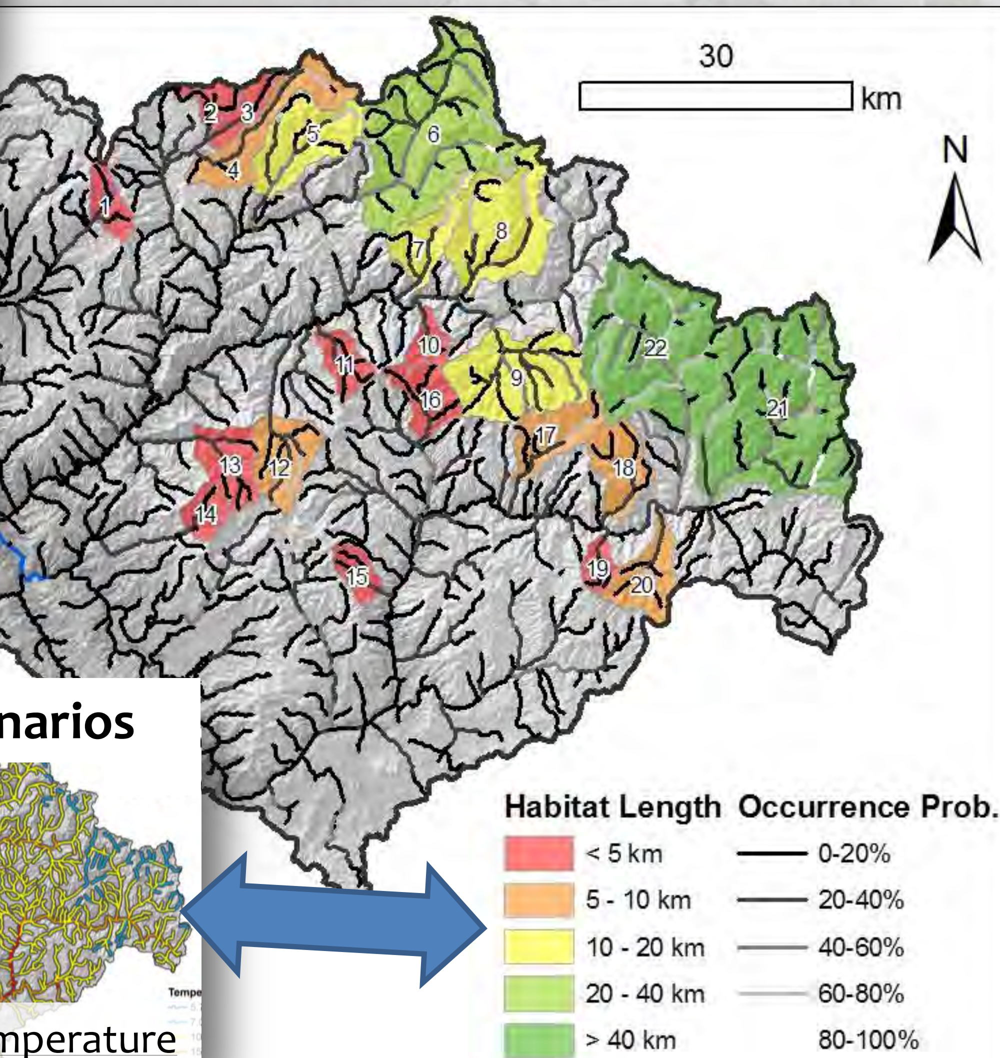
Better Spatial Data = Better Resource Decisions



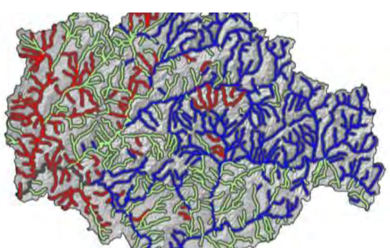
Bull Trout Climate Decision Support Tool

Tool runs on regionally consistent data layers

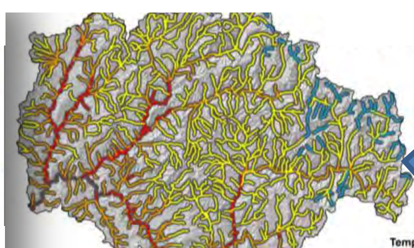




Downscaled Stream Scenarios



Streamflow

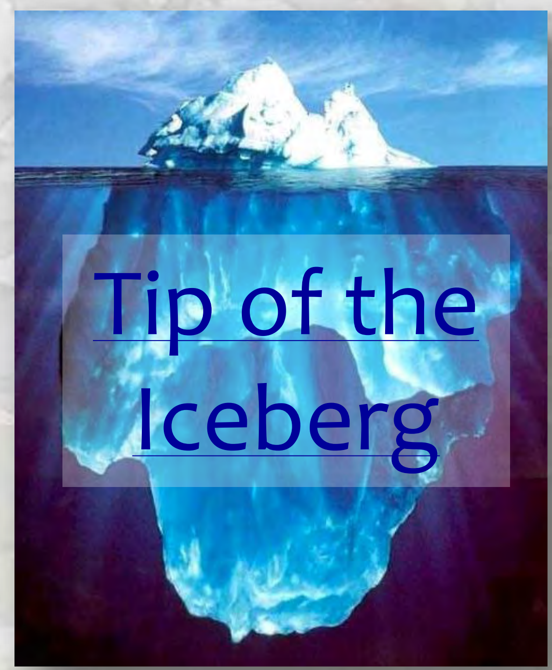


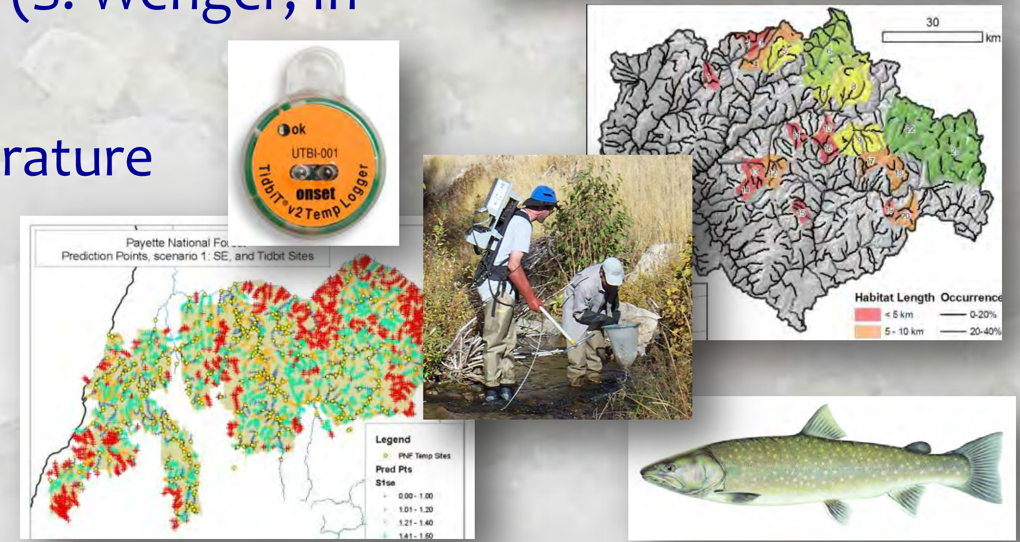
Stream Temperature

Peterson et al. 2013. *Fisheries* **38**:112-127.

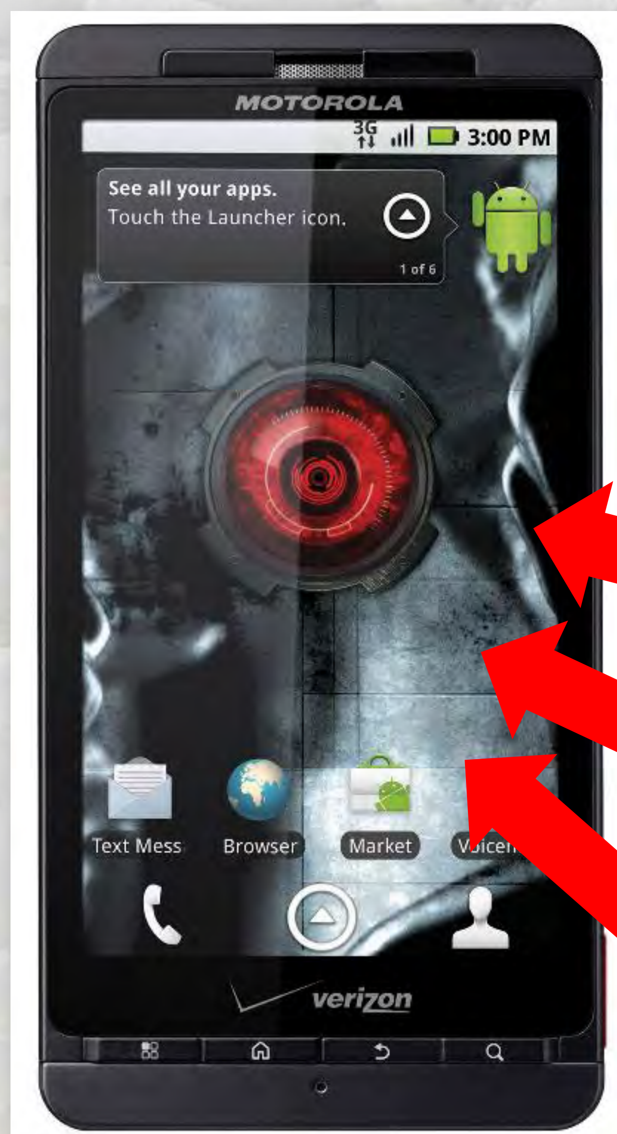
NorWeST Facilitating Related Projects

- 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, In Prep.)
- Efficient stream temperature monitoring designs

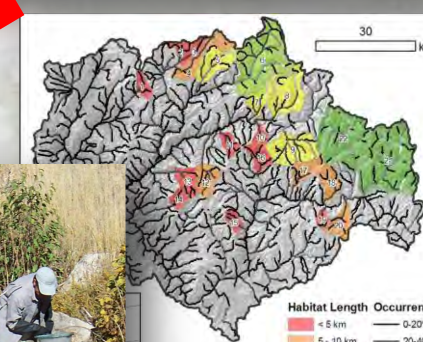


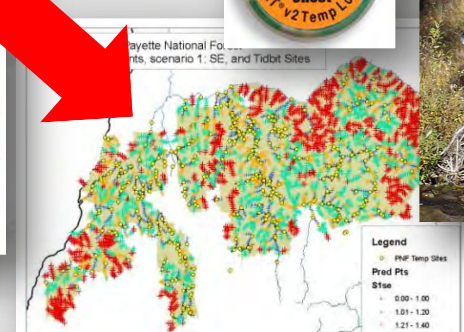


NorWeST Facilitating Related Projects



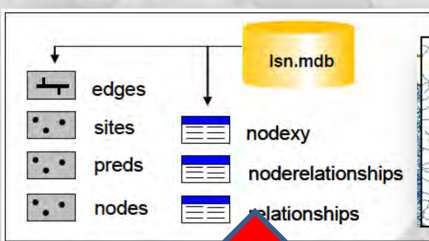
“Apps” Run on a Consistent Data Network

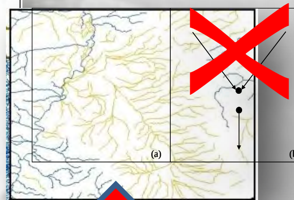


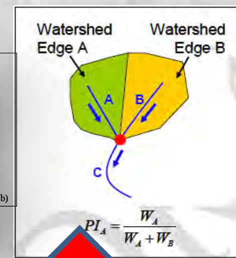


An InterNet for Stream Data

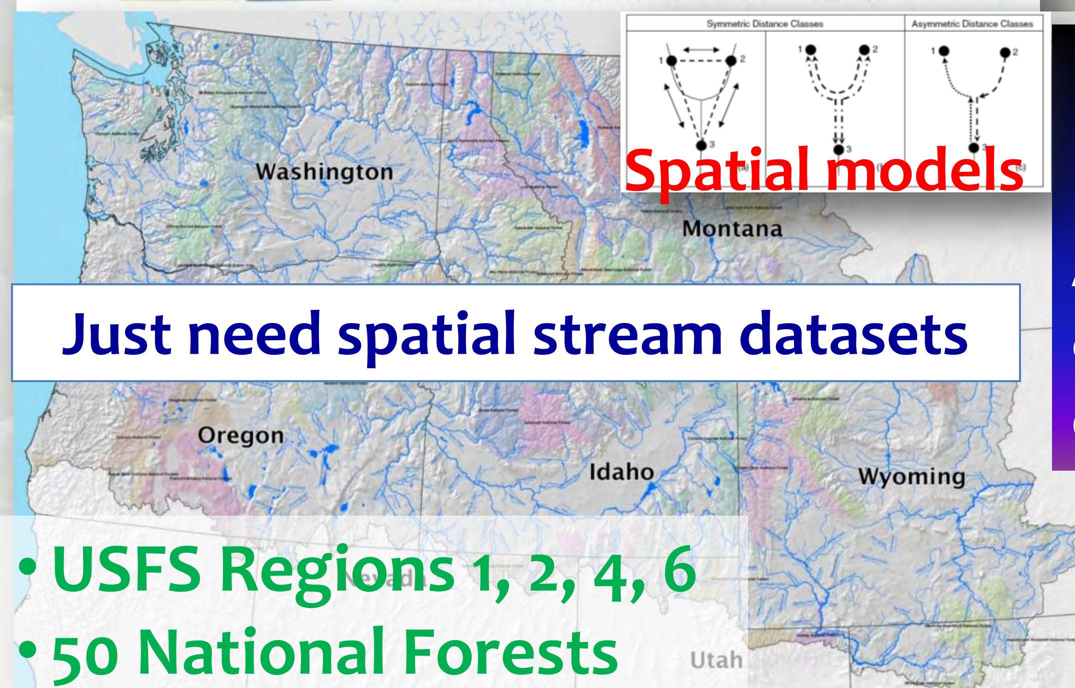
Technical & GIS infrastructure now exist







Great Northern
LANDSCAPE CONSERVATION COOPERATIVE



Spatial models

Just need spatial stream datasets

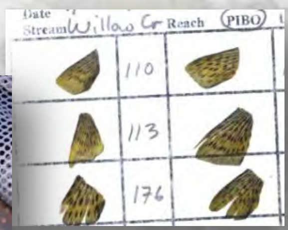
- USFS Regions 1, 2, 4, 6
- 50 National Forests

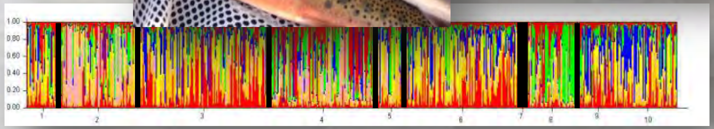
1G LCC

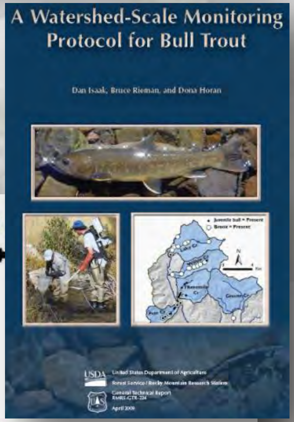
Accurate & consistent scaling of information

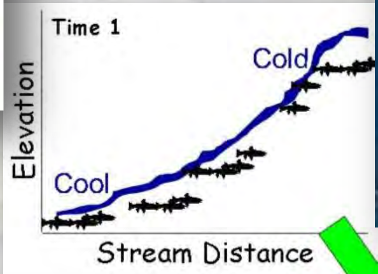
Internet Needs Consistent Data "Packets"

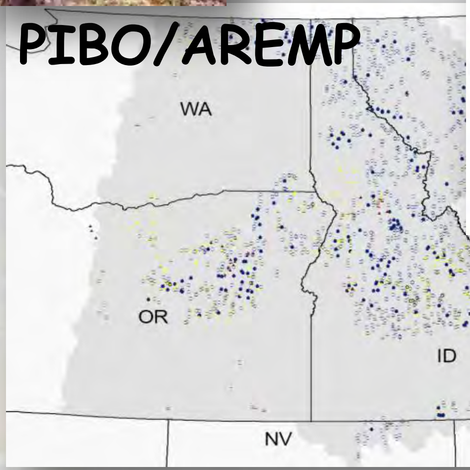
Standardized data collection protocols

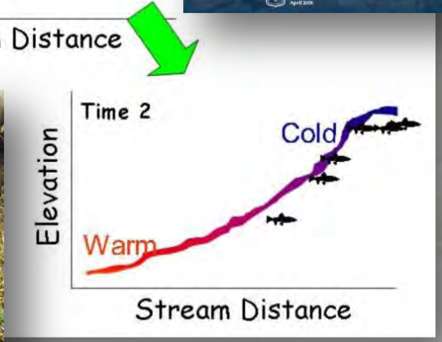








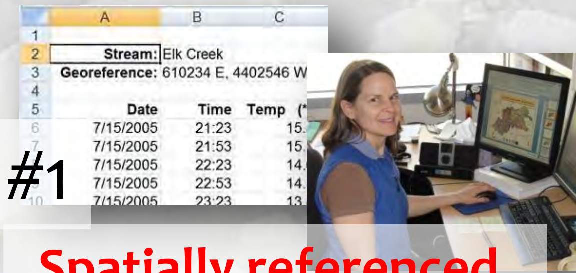




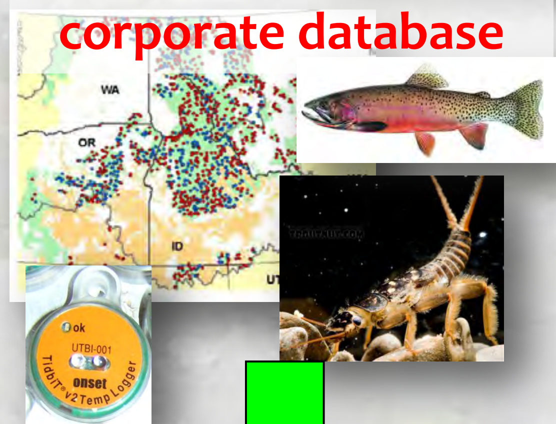
Data Needs to be Accessible

Data In → Information Out

#1



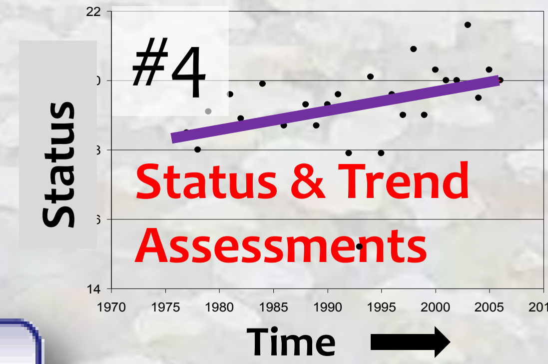
Spatially referenced, corporate database



Aquatic Surveys Module

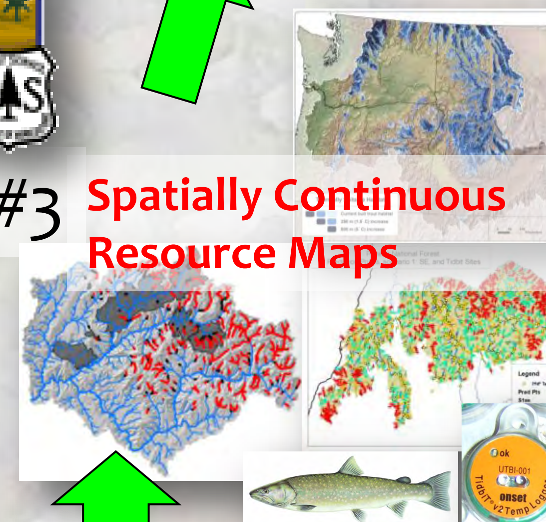
NRM

#4

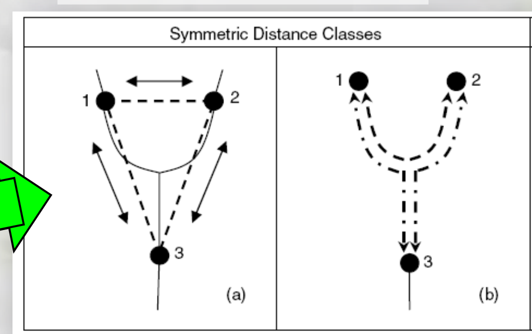


Status & Trend Assessments

#3 **Spatially Continuous Resource Maps**



#2 **Analysis**



#2a

More data, monitoring design

Let's Never Live this Nightmare Again

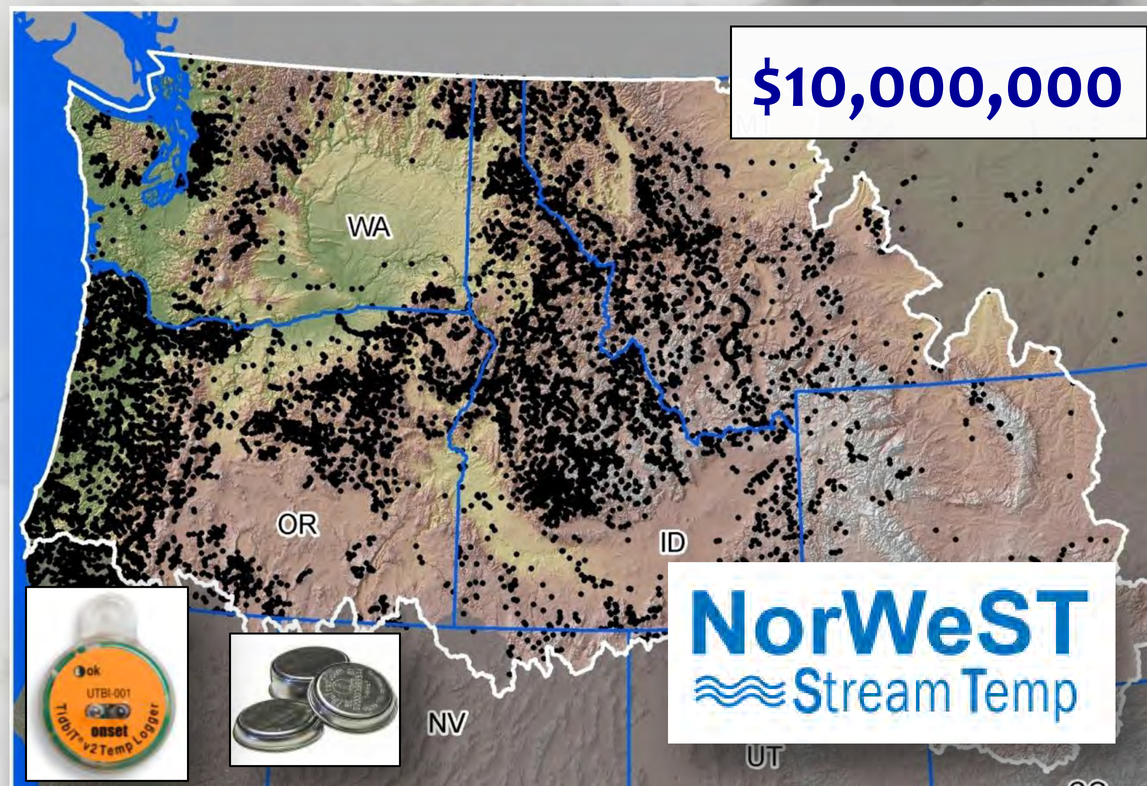
USFS has an awesome amount of data…

… that is awesomely disorganized

>45,000,000 hourly records
>15,000 unique stream sites
~50% data from USFS

We have millions of $'s in "free" data if organized

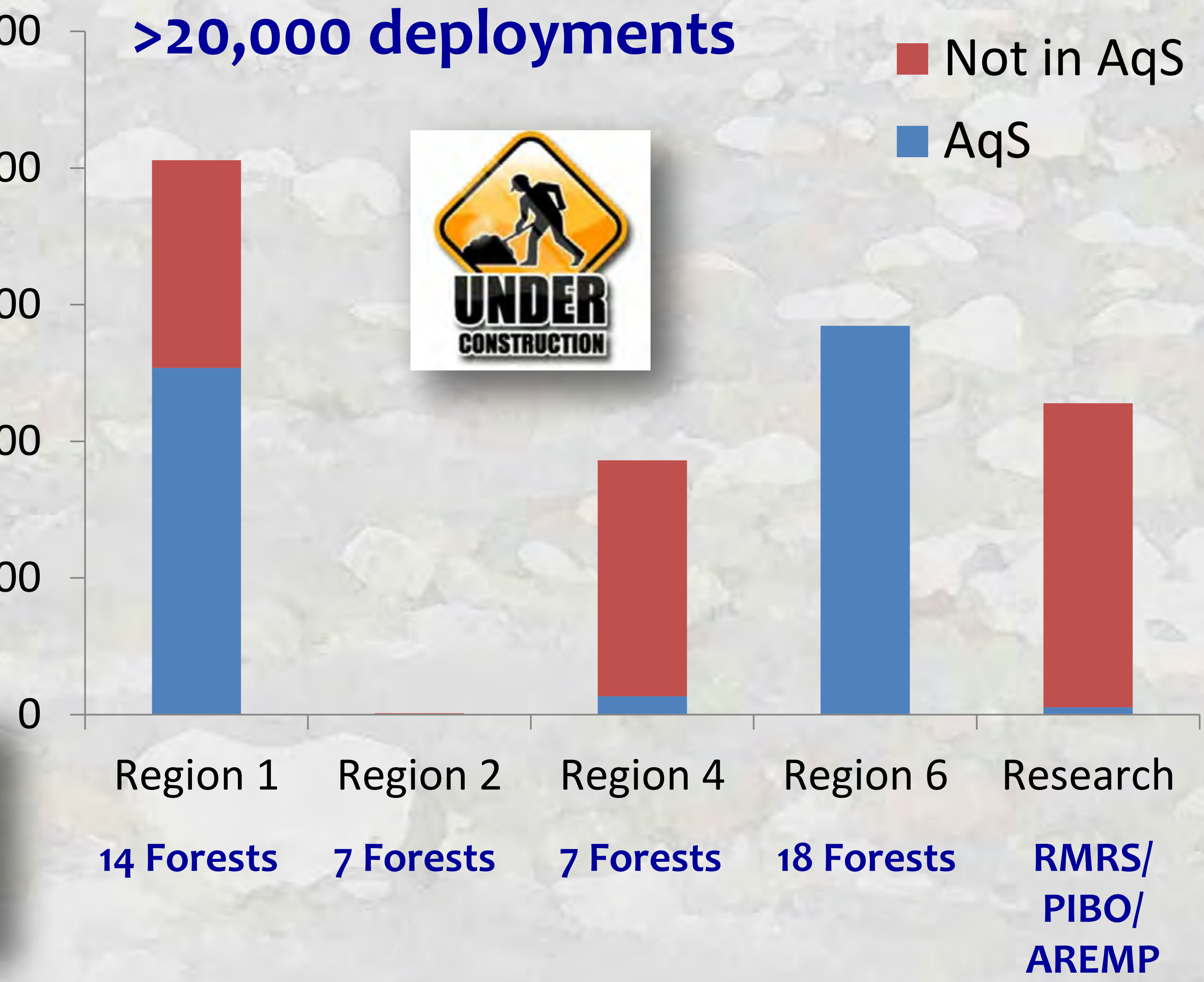
Biggest value is information developed from these data



$10,000,000

NorWeST Stream Temp

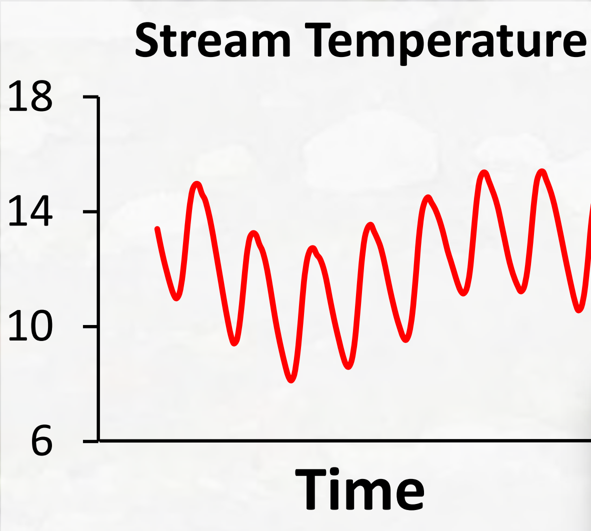
Legacy Temperature Data Migration for Forests in NorWeST area

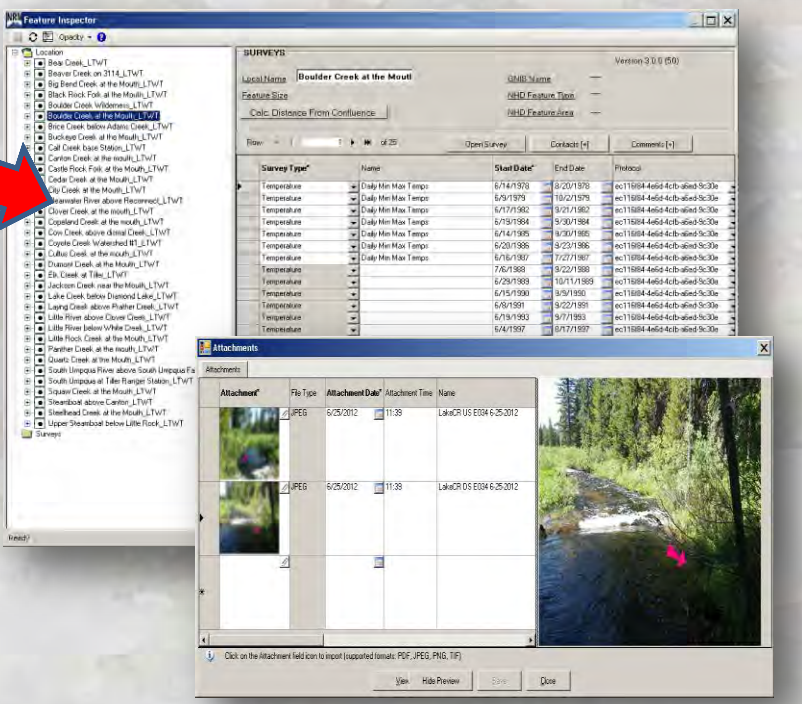


Aquatic Surveys Module in NRM

Temperature Surveys Tool in AqS

Data Entry, Uploading, Maintenance Interface





Callie McConnell's development team is superb

Surveys/database structure can be evolved

Research/Management Synergy

A Large Land-base

190 Million Acres

+

"Boots-on-the-Ground"

USFS has ~600 fish bios/hydros.
(That's an aquatics army!)

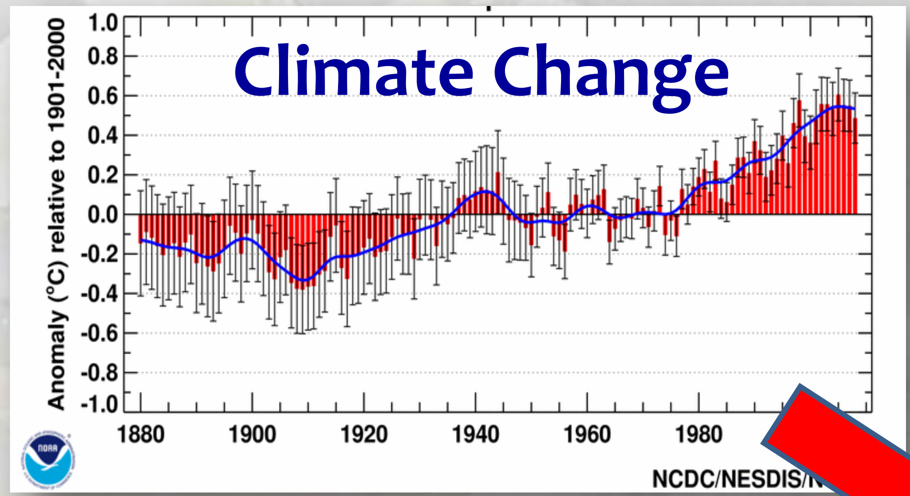
+

Lots of data
being collected

+

Research stations develop
information & connect people

More With Less, but What If… It was Much More?

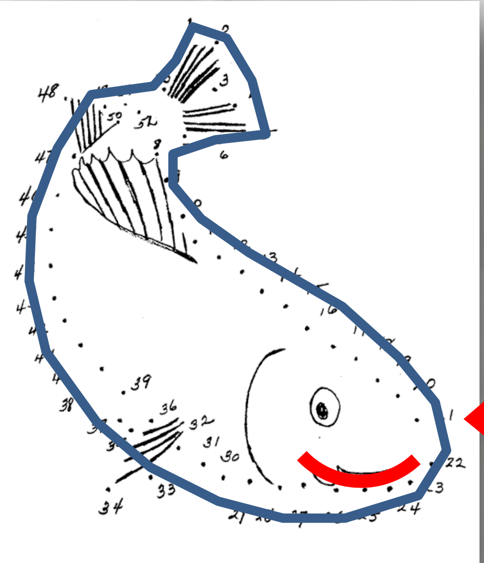


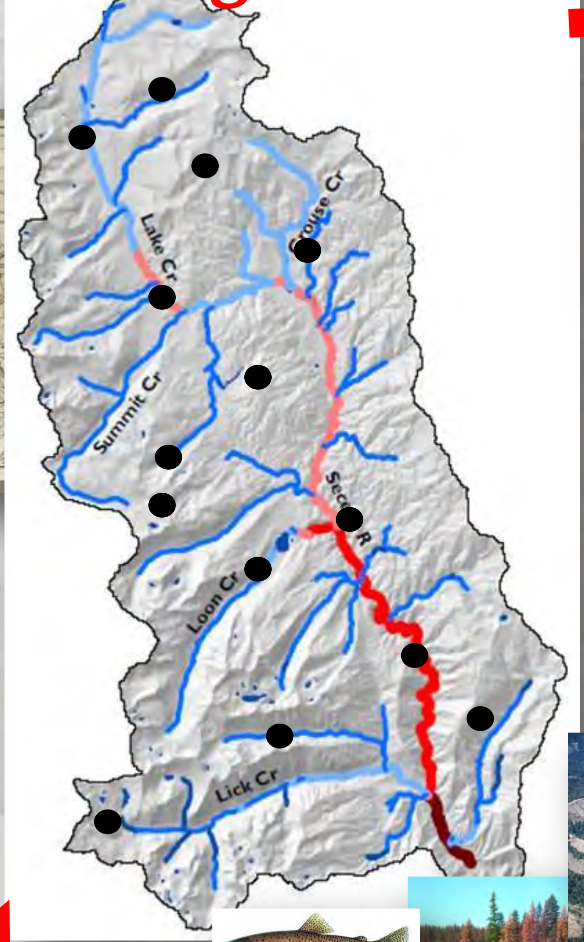
Urbanization & Population Growth

Shrinking Budgets

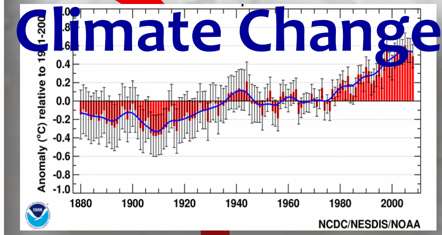
Connect the Dots ^ to Map the Future

& the People & the Agencies

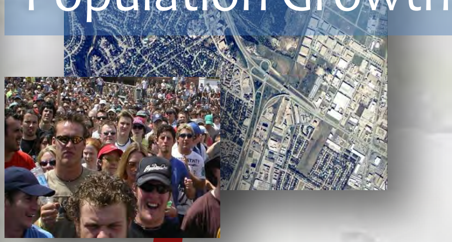


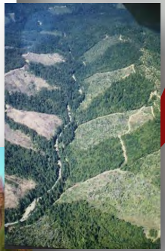


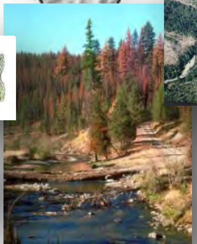
Climate Change



Urbanization & Population Growth







Land & Species Management

Find me on facebook

stream