Space… The Final Stream Frontier

Ecology, 74(6), 1993, pp. 1659–1673

SPATIAL AUTOCORRELATION: TROUBLE OR NEW PARADIGM?[1]

PIERRE LEGENDRE
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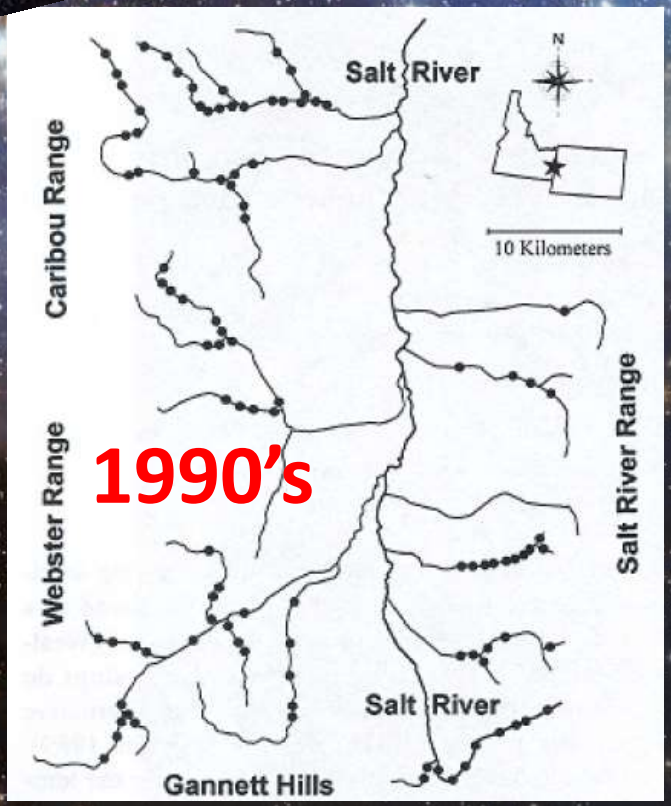


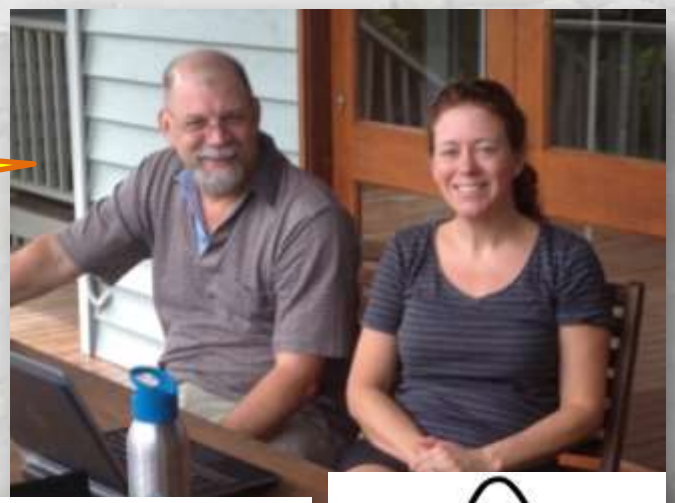
Statistical Models for Data on Stream Networks… FINALLY!

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

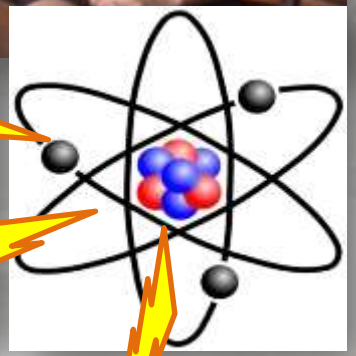
Jay M. Ver Hoef · Erin Peterson · David Theobald

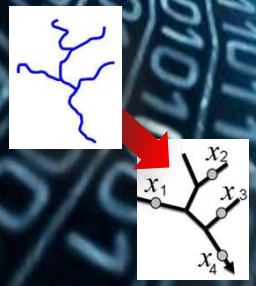


Ecology, 91(3), 2010, pp. 644–651

A mixed-model moving-average approach to geostatistical modeling in stream networks

Erin E. Peterson[1,3] and Jay M. Ver Hoef[2]

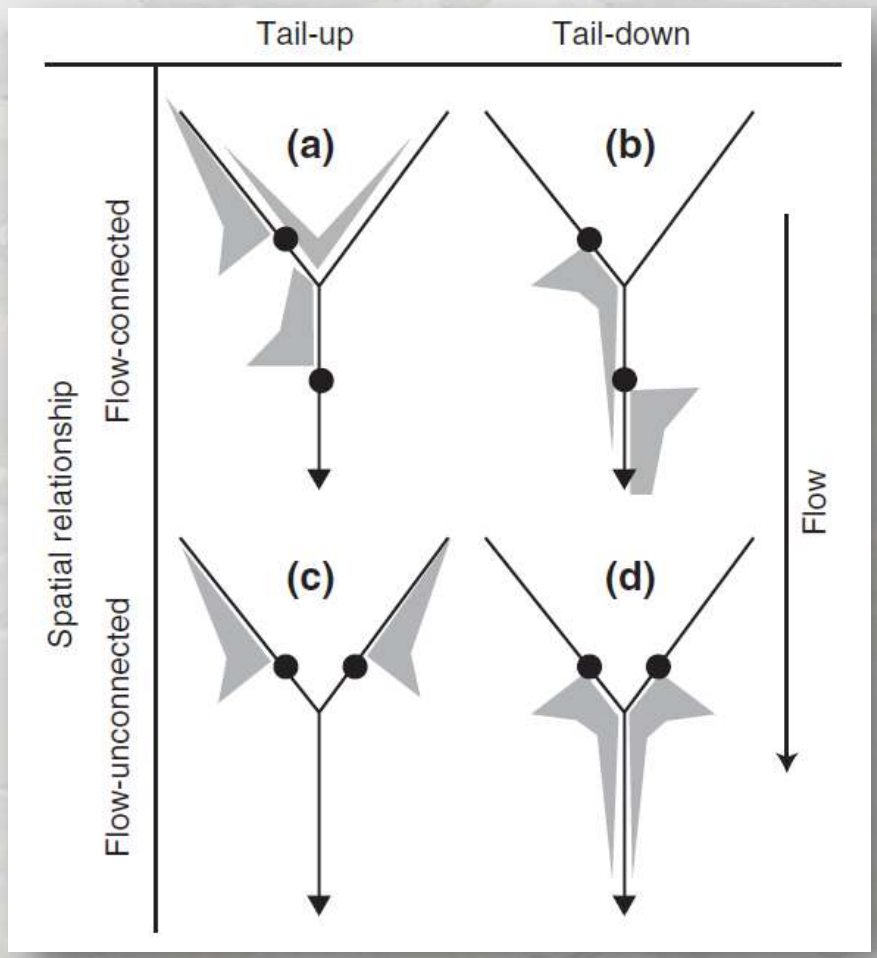


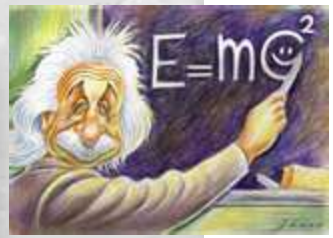


A Moving Average Approach for Spatial Statistical Models of Stream Networks

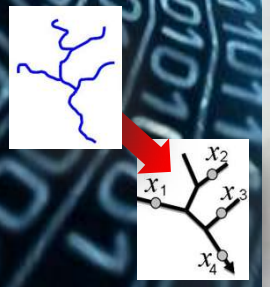
Jay M. Ver Hoef and Erin E. Peterson

Key Innovation is Covariance Structure Based On Network Structure





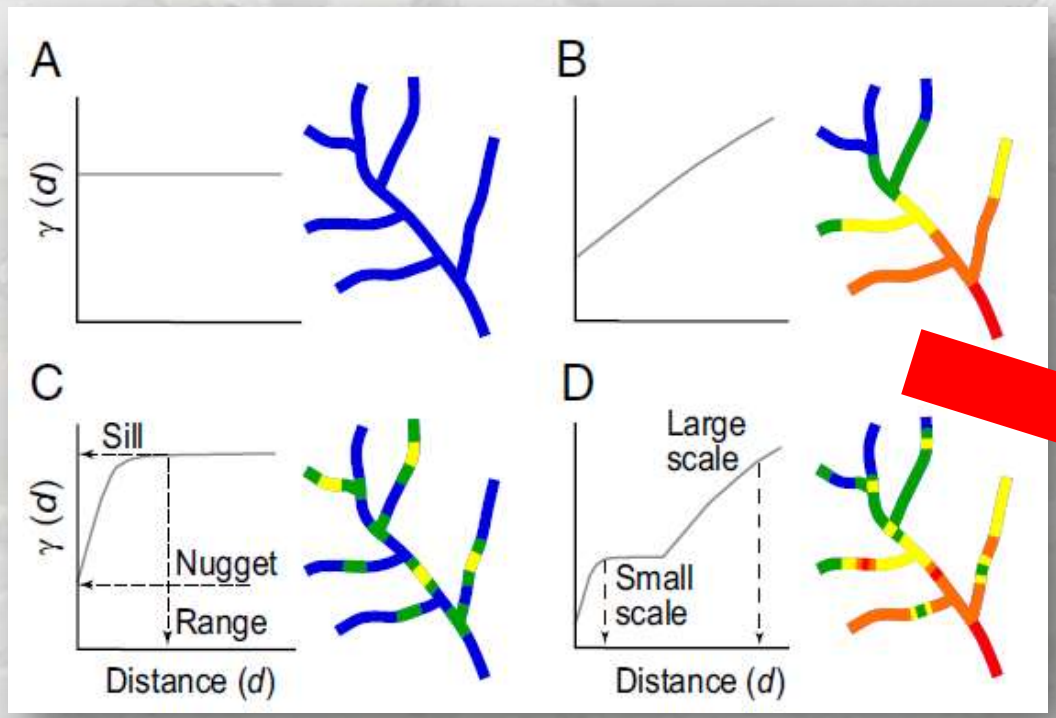
- **Models "understand" how information moves among locations**
- **Models account for spatial autocorrelation among observations**

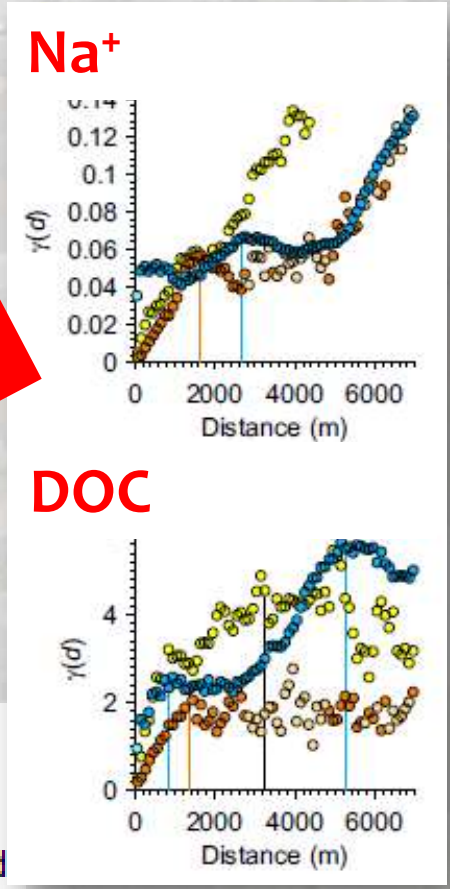


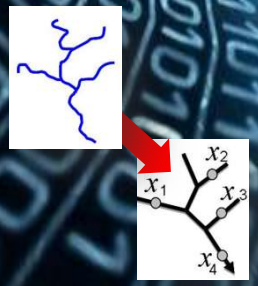
Peterson et al. 2007. *Freshwater Biology* **52**:267-279;
Peterson & Ver Hoef. 2010. *Ecology* **91**:644-651.

Pattern Description & Data Exploration

Torgegram ~ Semivariogram

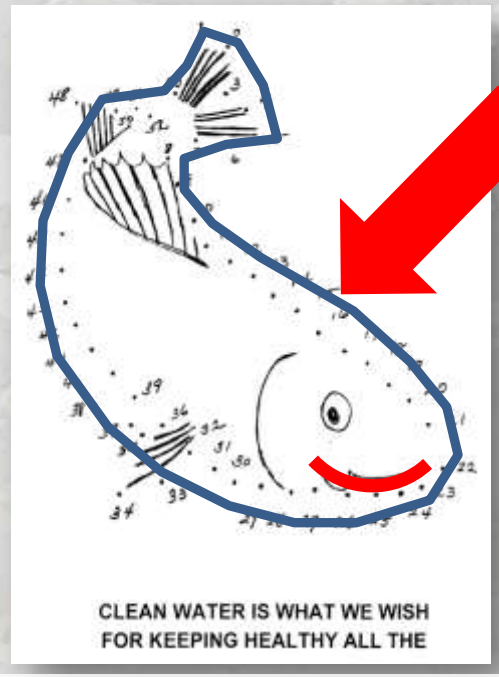




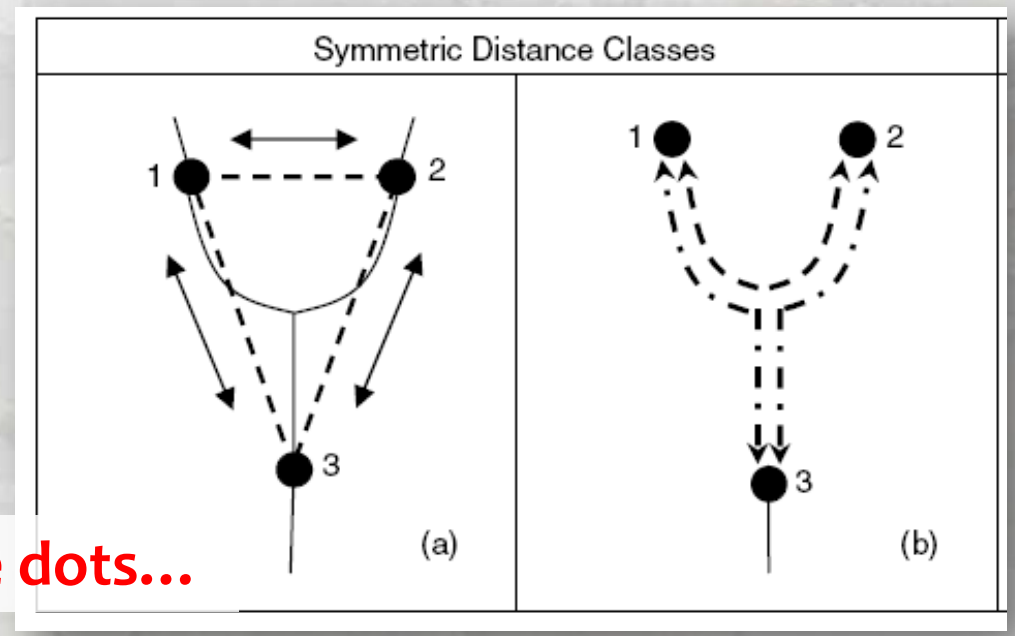


McGuire et al. 2014. Network analysis reveals multiscale controls on streamwater chemistry. *PNAS* doi: 10.1073/pnas.1404820111

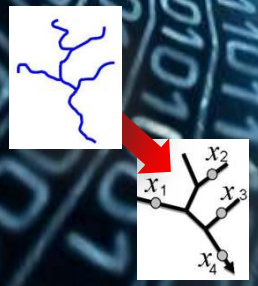
Predictive Models with Covariates



Valid Interpolation on Networks



Let's us connect the dots…



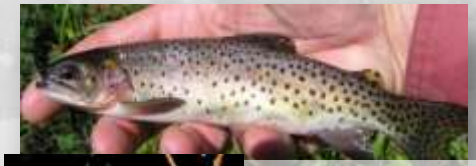
Advantages:

-flexible & valid covariance structures by accommodating network topology

-weighting by stream size

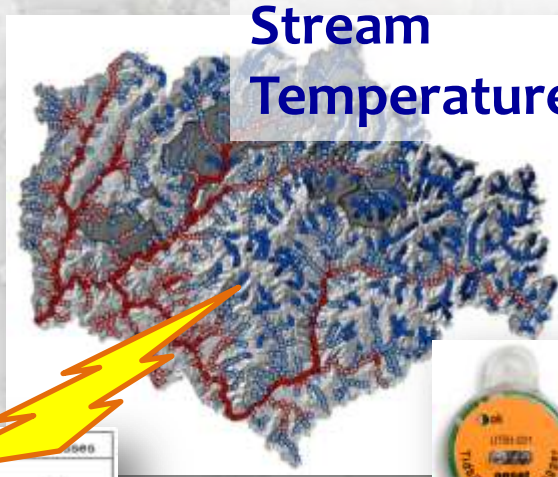
-improved predictive ability & parameter estimates relative to non spatial models

Stream Models are Generalizable…

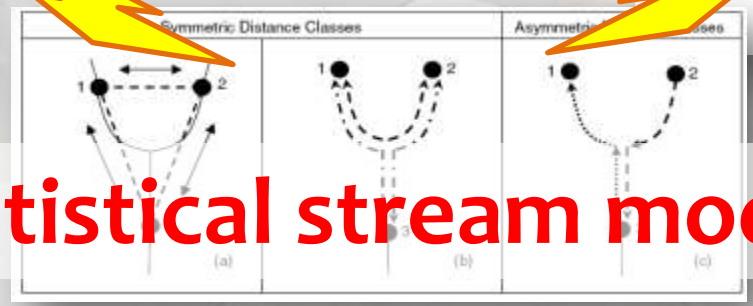


Distribution & abundance

Response Metrics
- Gaussian
- Poissan
- Binomial

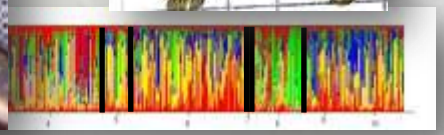


Stream Temperature

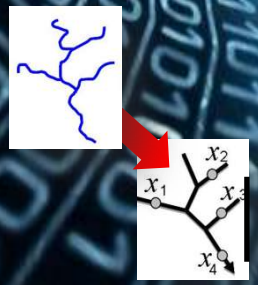


Statistical stream models

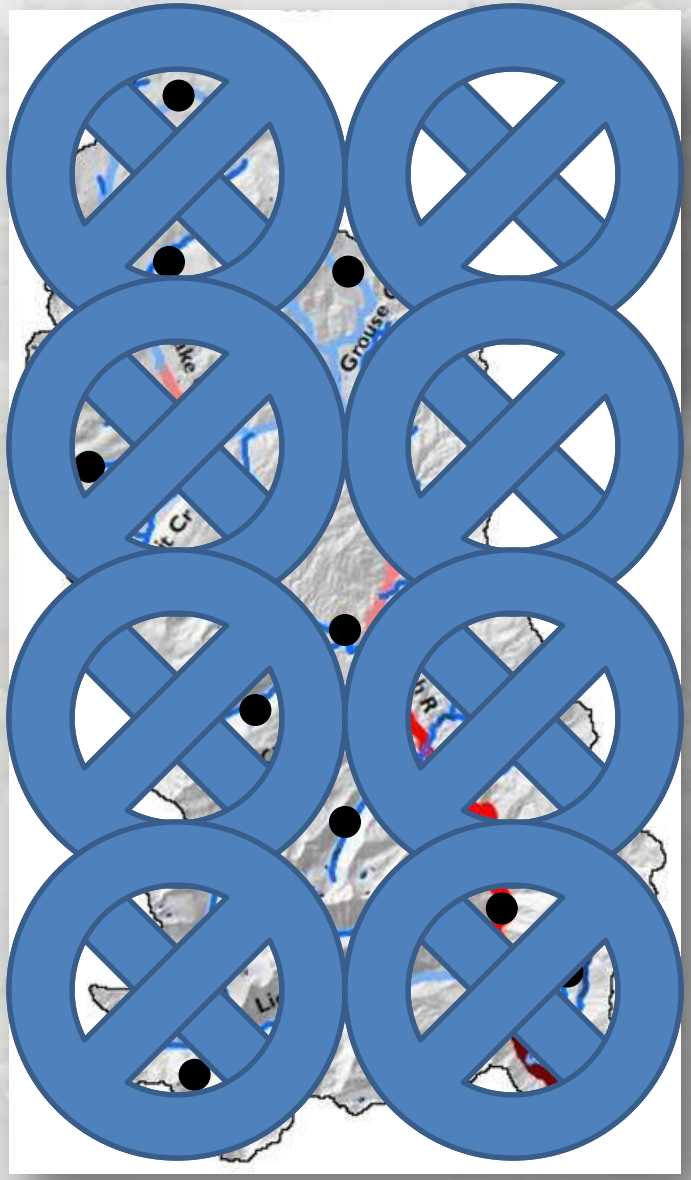
Genetic Attributes

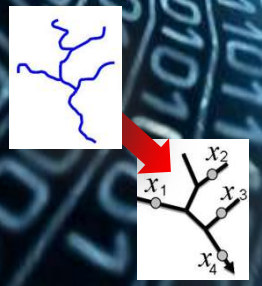


Water Quality Parameters



Stop Viewing Streams as Dots





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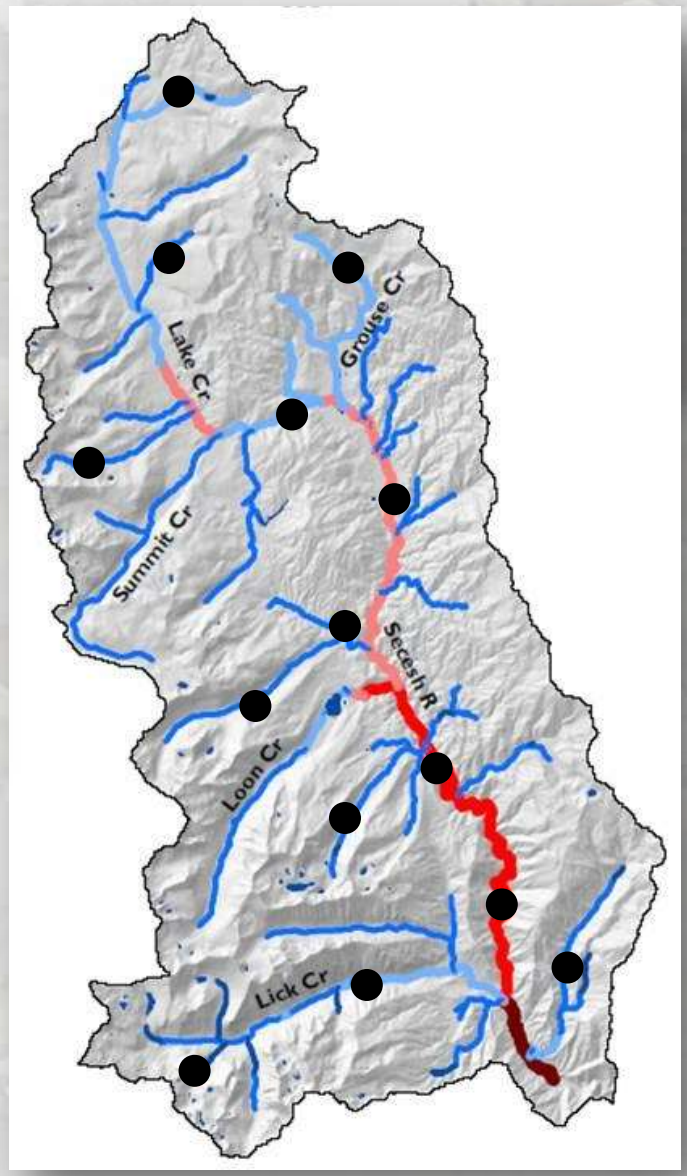
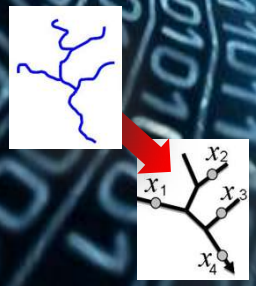
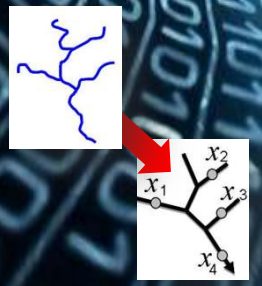
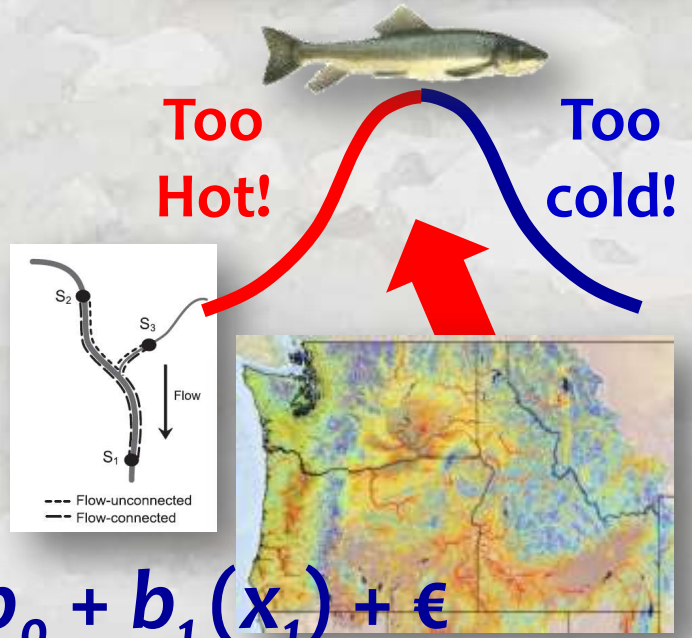




Applications of Stream Network Models

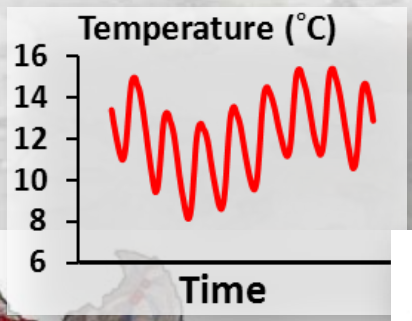
- Parameter estimation & prediction
- Status & trend assessments
- Efficient monitoring designs
- Block-kriging for reference site comparisons & fish population estimates
- Mining of BIG DATA databases
  - Climate scenarios
  - Temperature criteria
  - Species distribution models



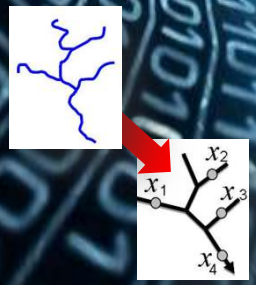


$$Y = b_0 + b_1(x_1) + \epsilon$$

Developing a River Network Temperature Model – Boise River Basin



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



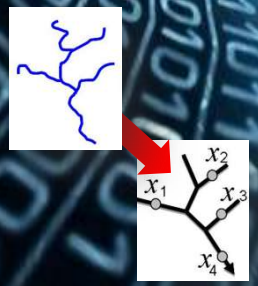
Watershed Characteristics
Elevation range 900 – 3300 m
Fish bearing streams ~2,500 km
Watershed area = 6,900 km^2

Accurate & Precise Information from a Crowd-Sourced, Interagency Database

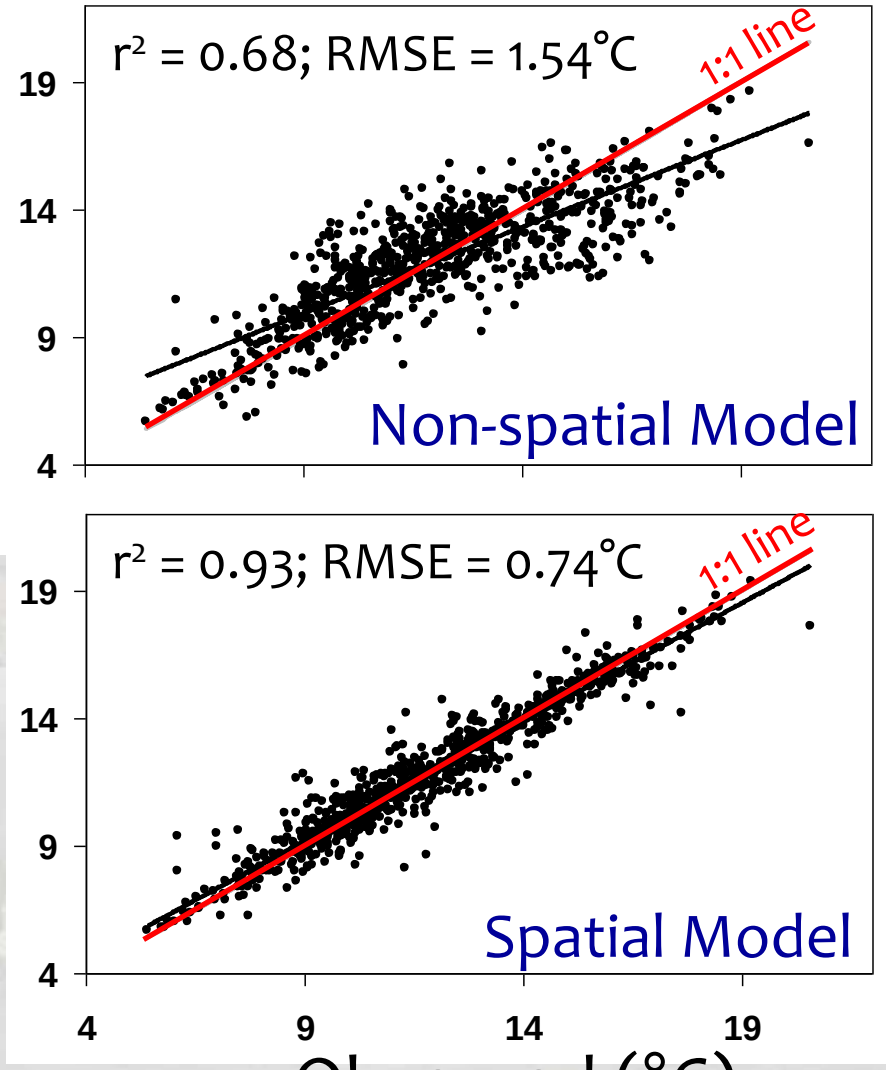
Non-spatial Stream Temp =
– 0.0064*Elevation (m)
+ 0.0104*Radiation
+ 0.39*AirTemp (°C)
– 0.17*Flow (m^3/s)

Autocorrelation effects on parameter estimates

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



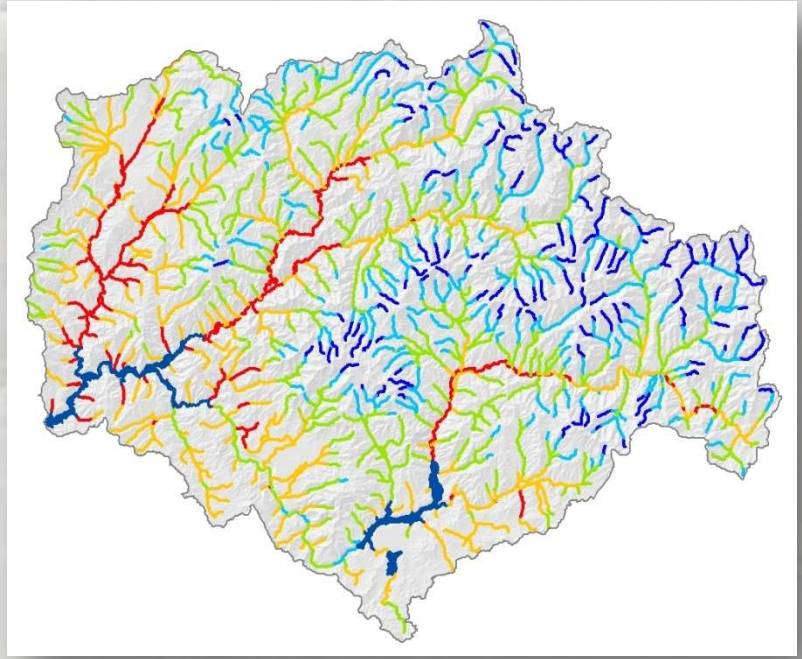
Mean Summer Stream Temp

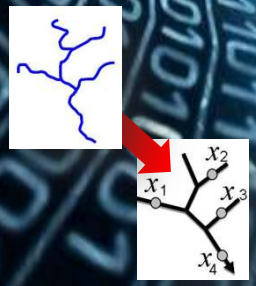


Isaak et al. 2010. *Ecol. Apps.* 20:1350-1371

Interpolated Predictions Provide High-Resolution Network *Status* Maps

Time 1





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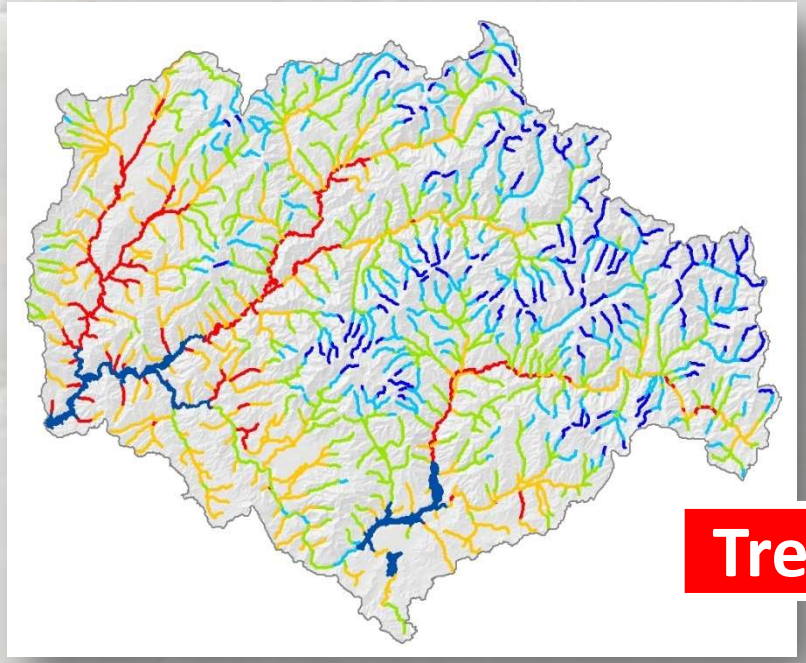
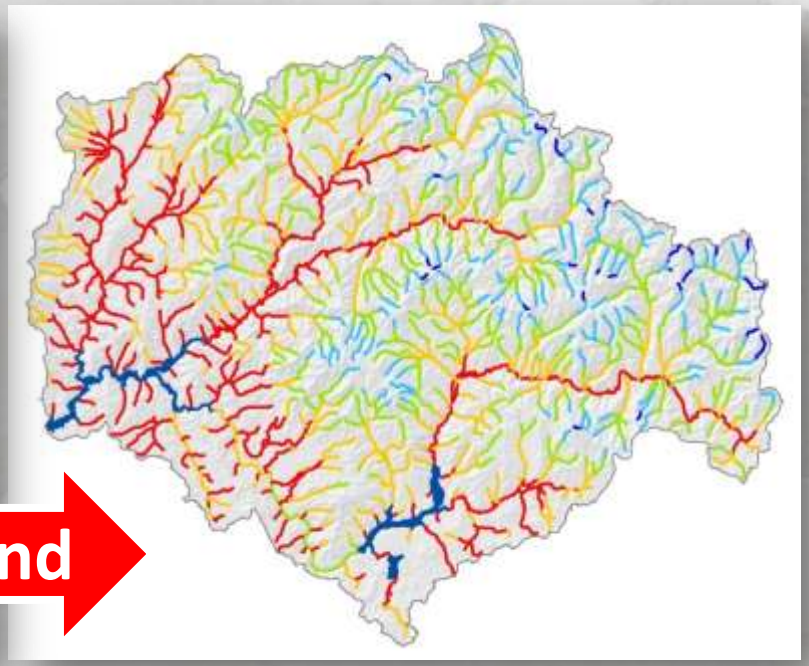
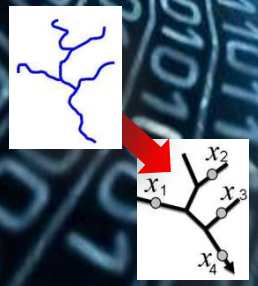


Time 2

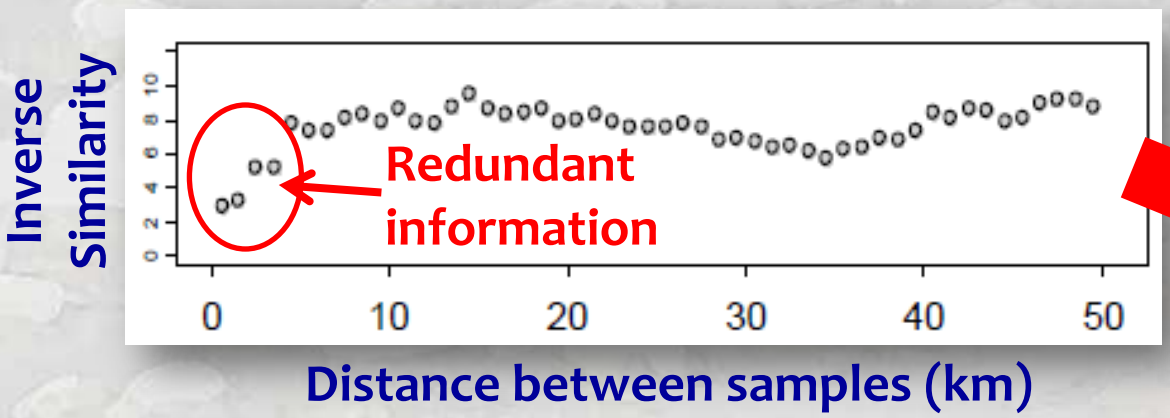


Trend

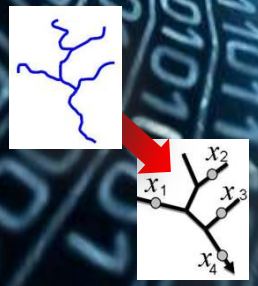
Which sets the stage for *trend* assessments…



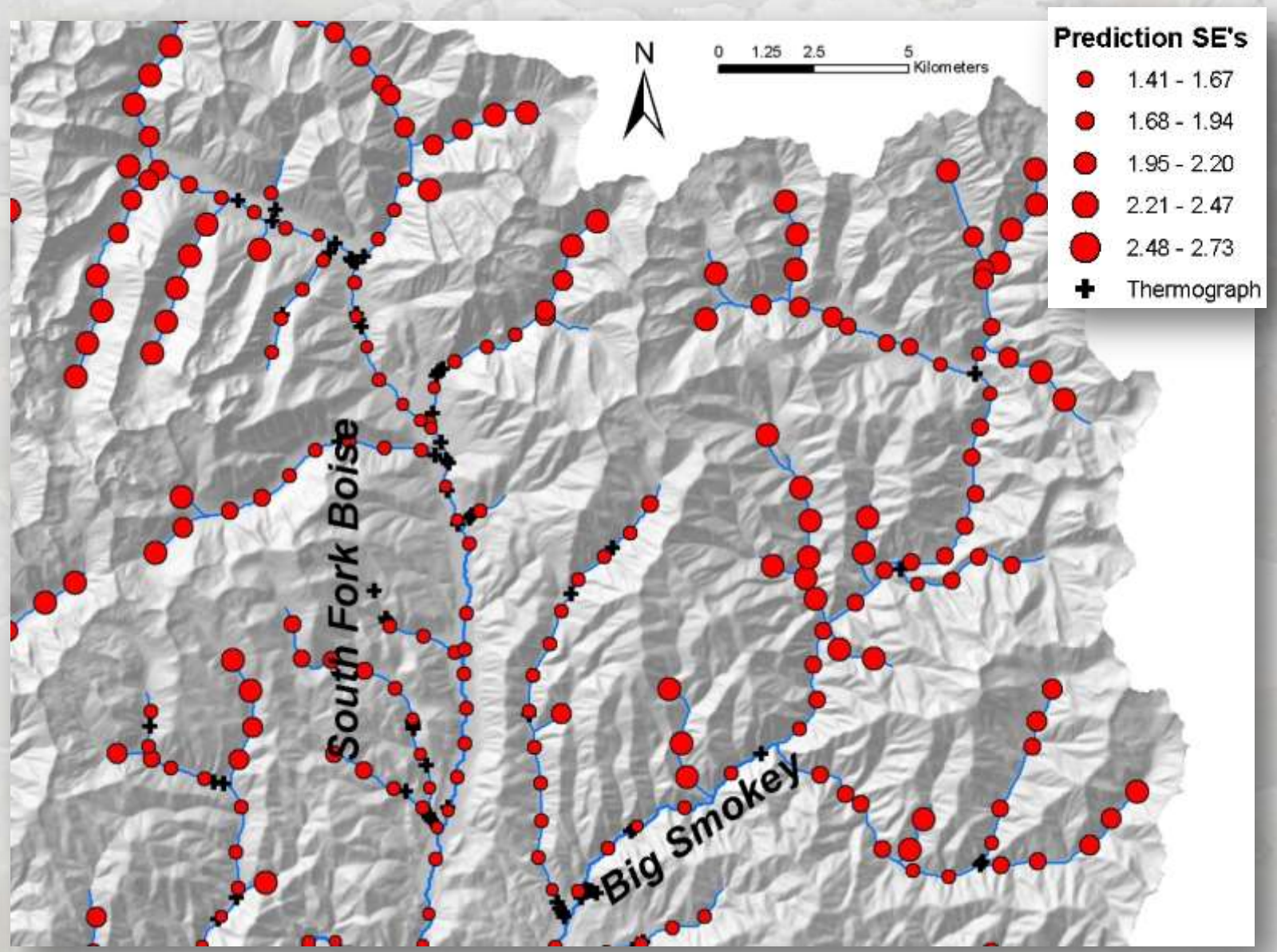
Models Describe Autocorrelation Distances

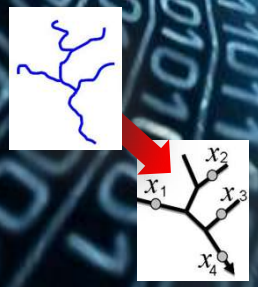


Planning of Efficient Monitoring Designs…



Spatial Variation in Prediction Precision

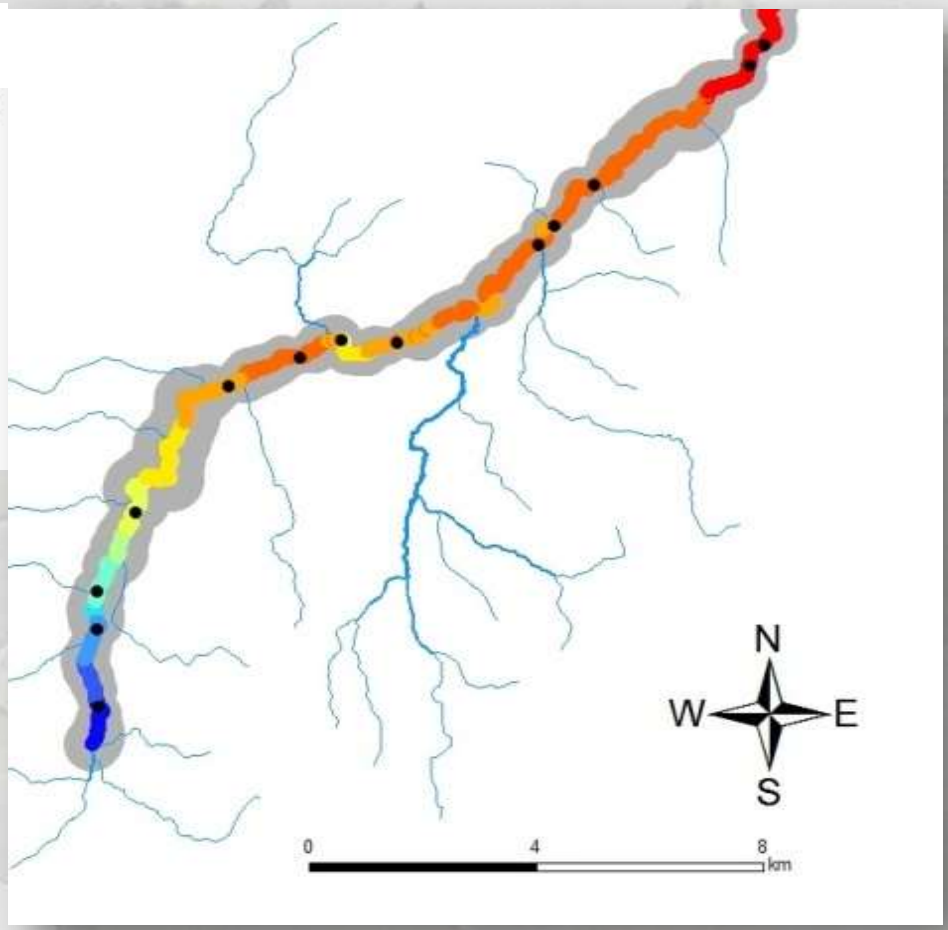


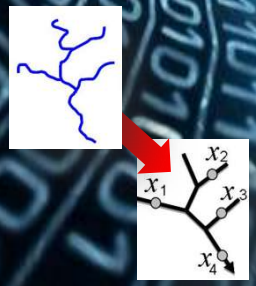


Block-krige Estimates of Mean & Variance at User-Defined Scales

Temperature (°C)

	95% CI (°C)
10.6 - 11.0	0.1
11.1 - 11.5	0.25
11.6 - 12.0	0.5
12.1 - 12.5	0.75
12.6 - 13.0	1
13.1 - 13.5	
13.6 - 14.0	
14.1 - 14.5	
14.6 - 14.9	





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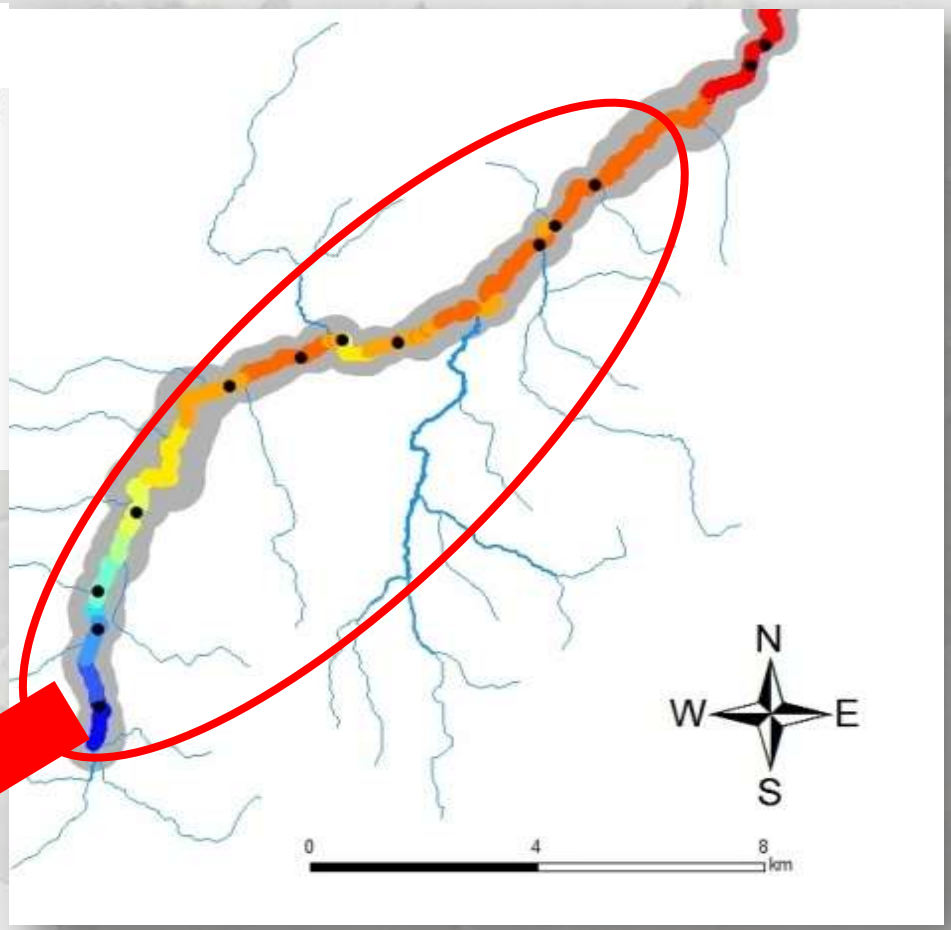
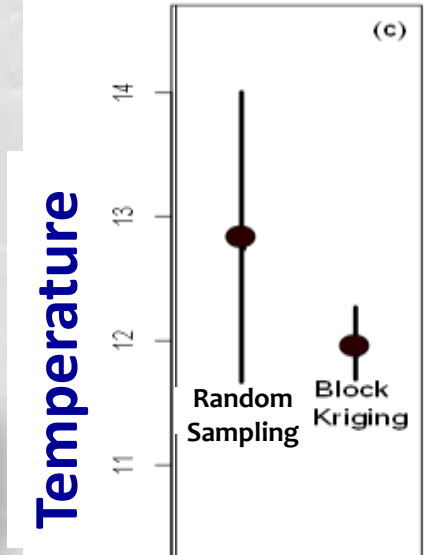
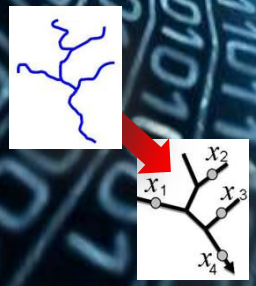
14.6 - 14.9	



Bear Valley Creek Mean Temperature





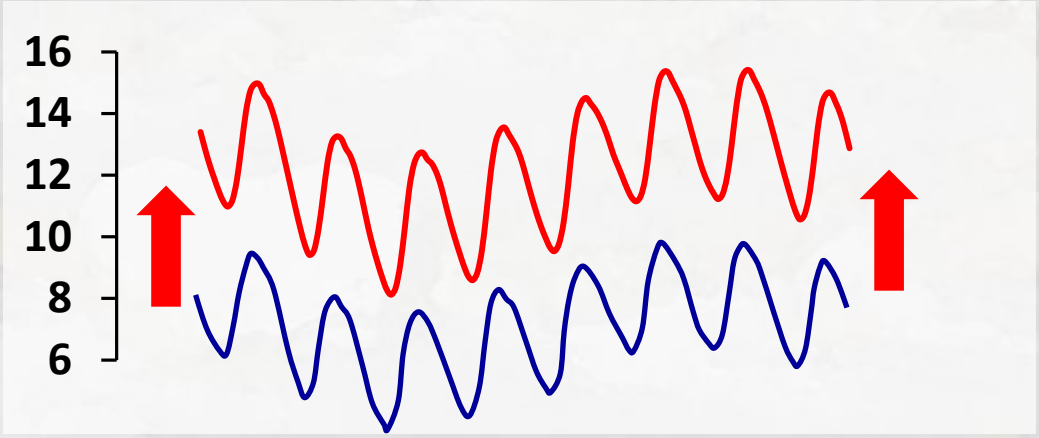
Precise & unbiased estimates

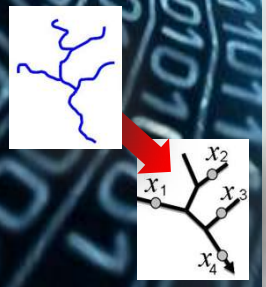
Does this reach meet the TMDL standard?

Reference Site Comparison Approach

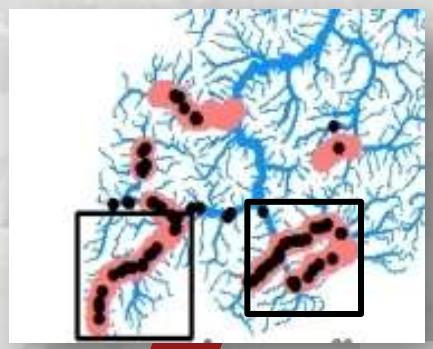
Pick “degraded” & “healthy” streams to compare

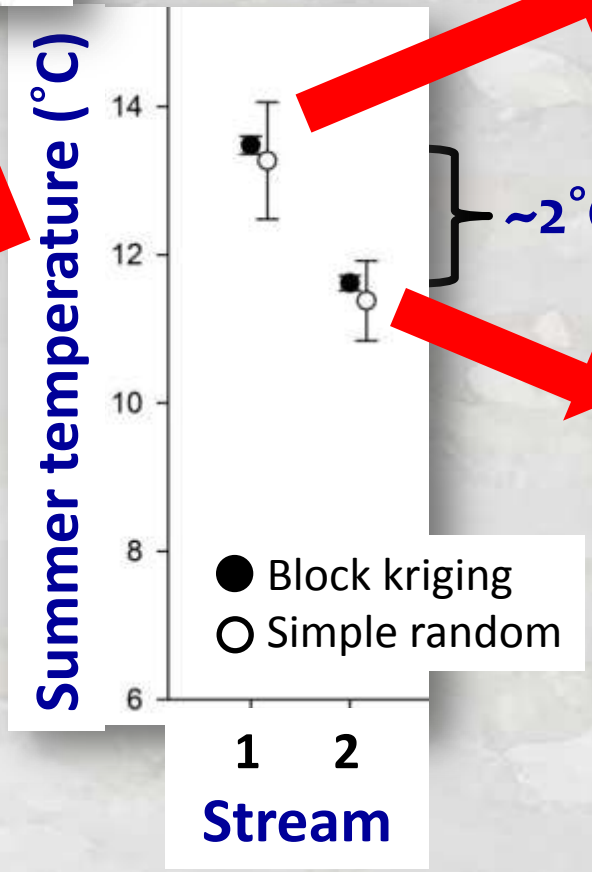
How altered is this stream?



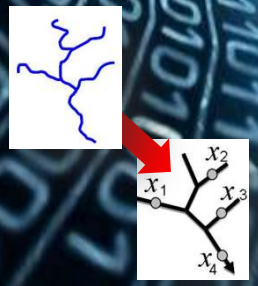


Block-Krige Estimates for Both Streams





~2°C difference



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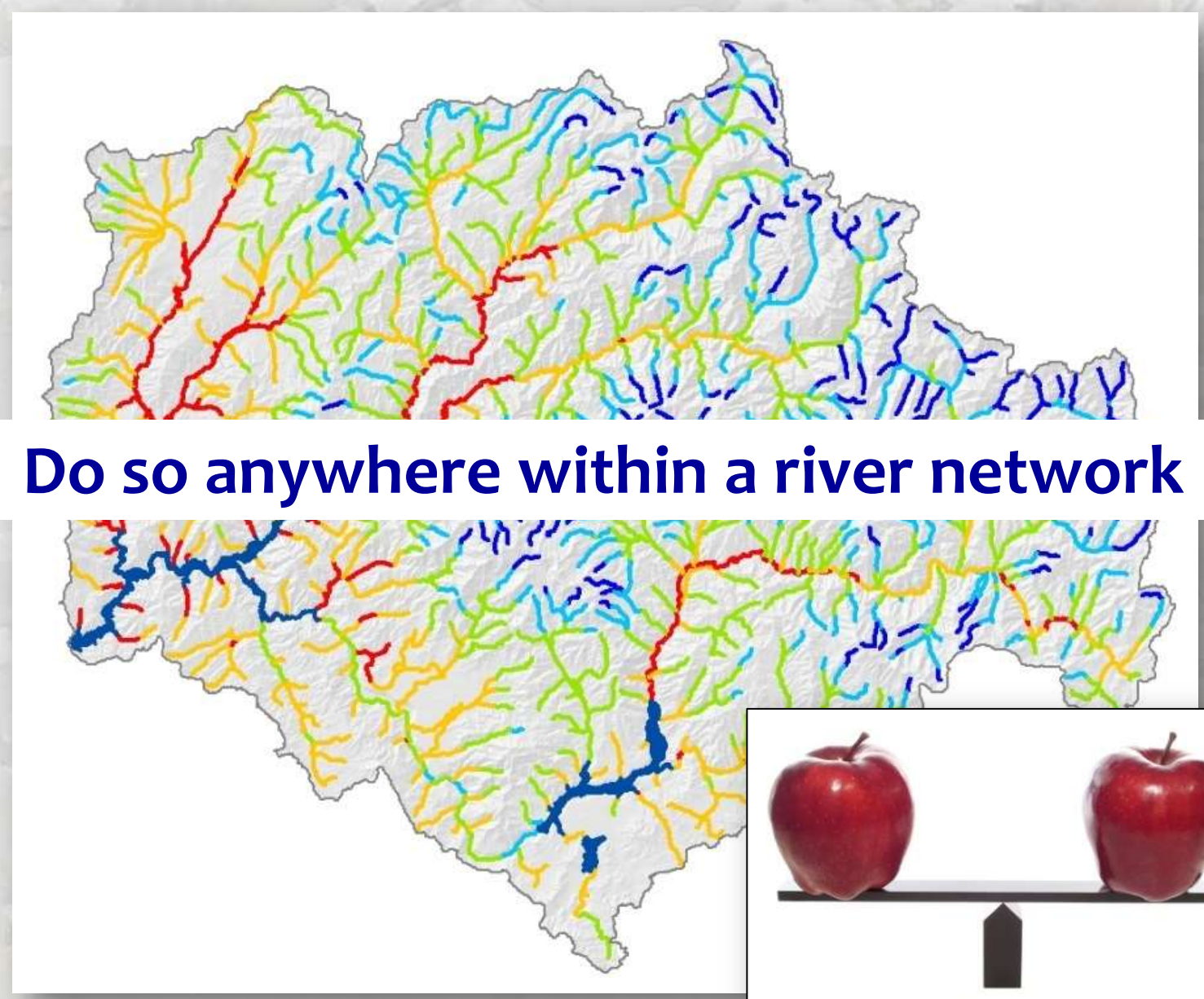
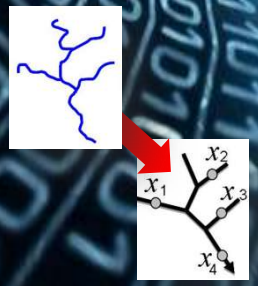
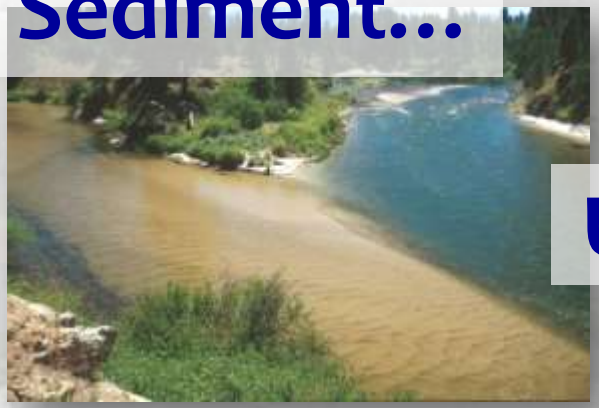


Do so anywhere within a river network



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

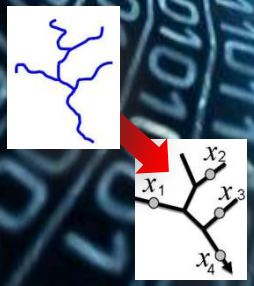
Sediment…



Urban runoff…

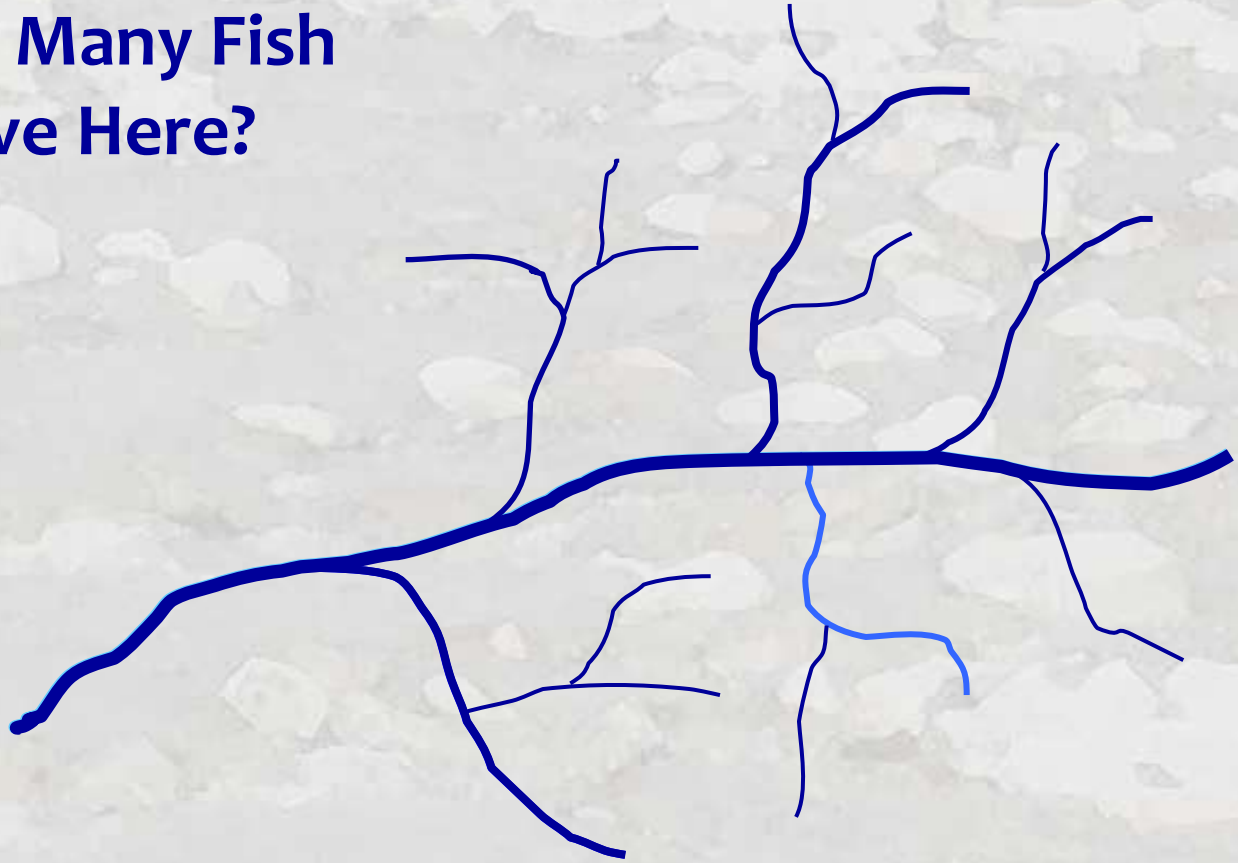
Nutrients…

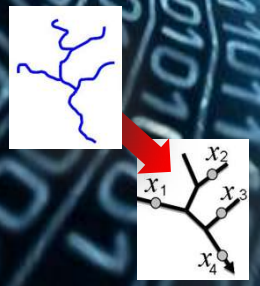
Mining…



Block-Kriging Fish Population Estimates

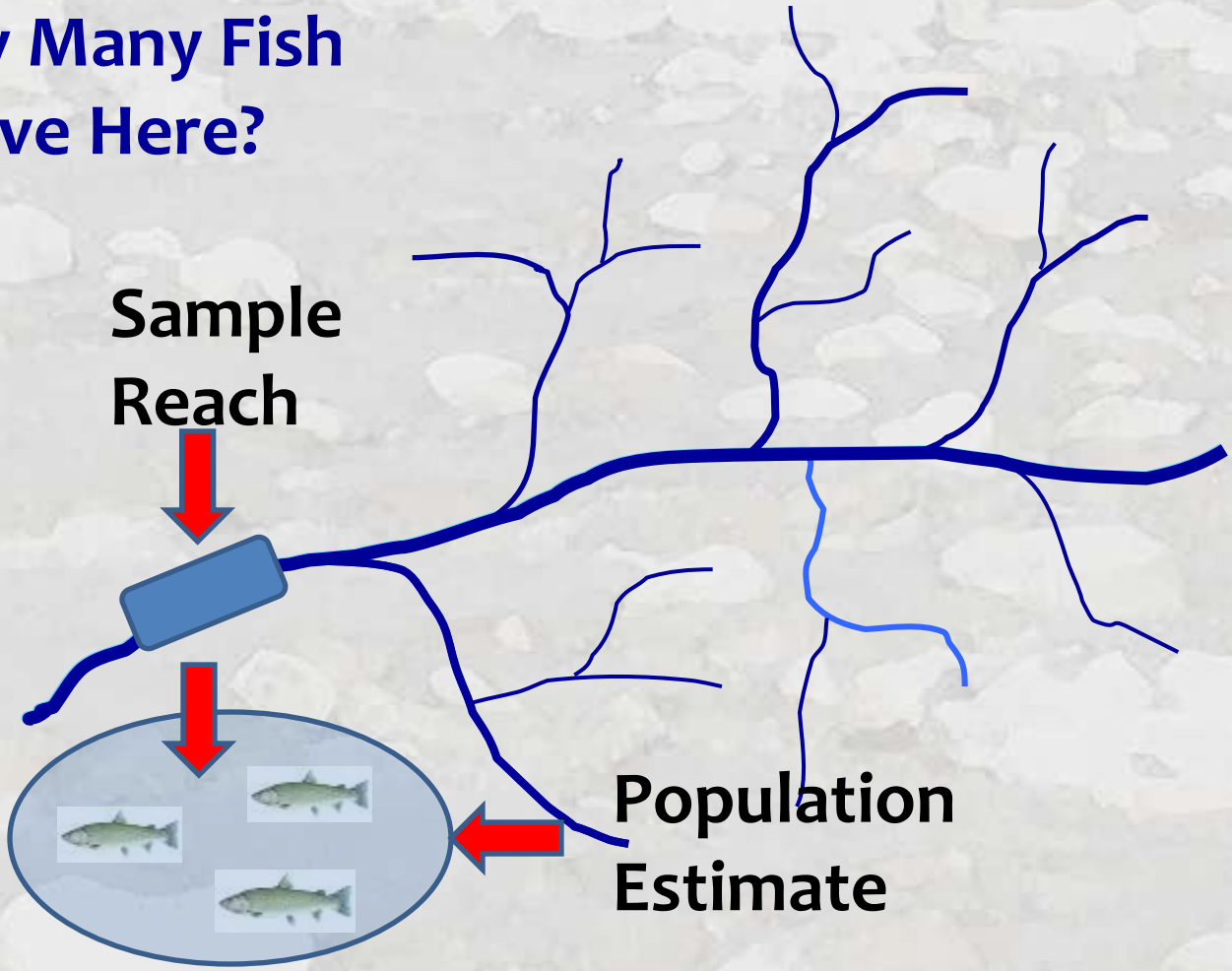
How Many Fish Live Here?

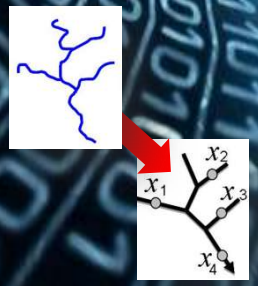




Block-Kriging Fish Population Estimates

How Many Fish Live Here?

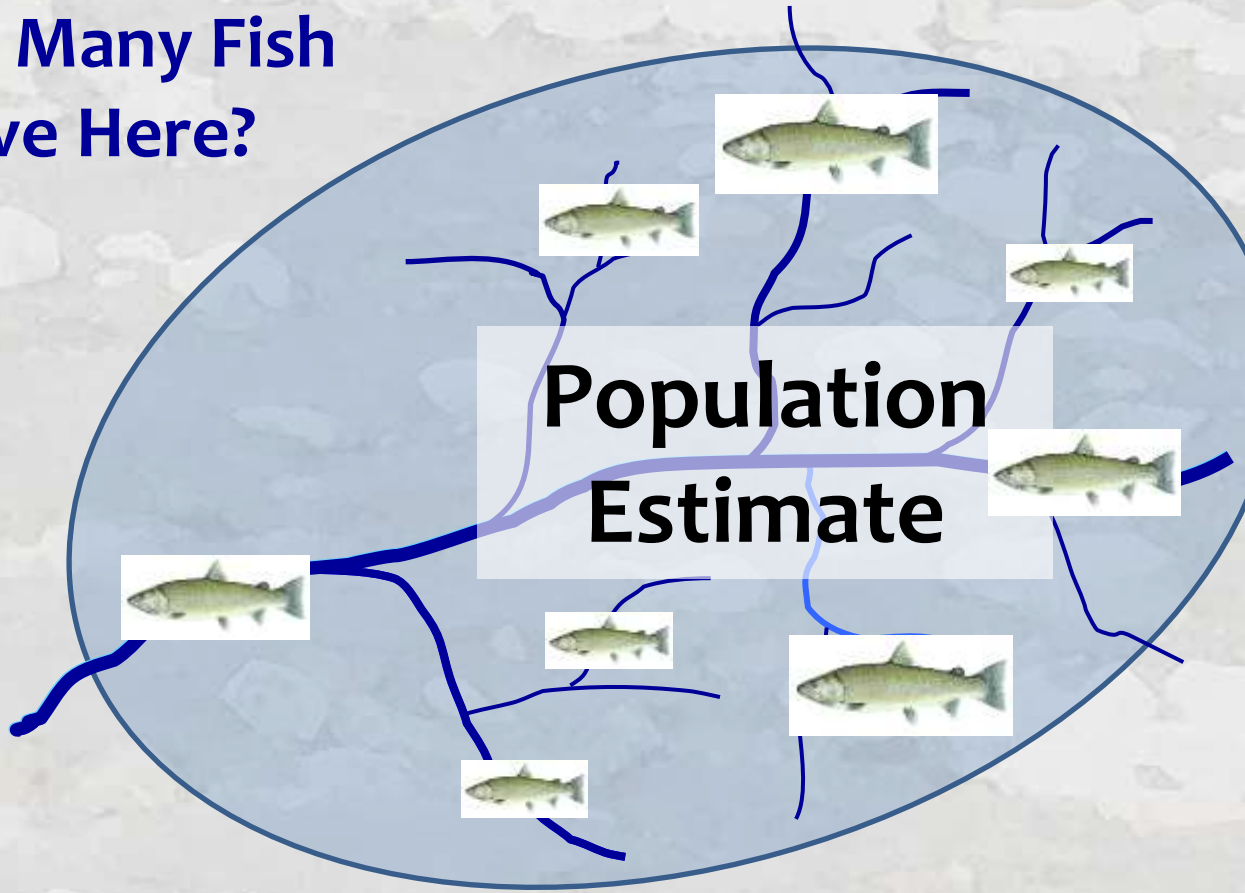


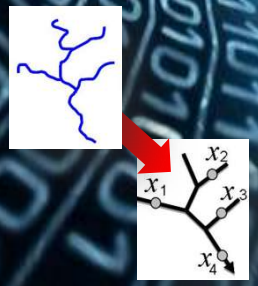


Traditional Estimation Scale = Reach (10's – 100's meters)

Block-Kriging Fish Population Estimates

How Many Fish Live Here?





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

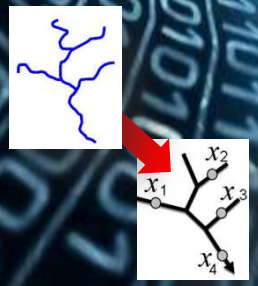
Block-Kriging Fish Population Estimates

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

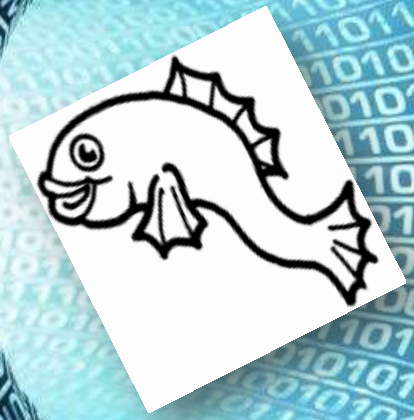
Spatial methods for plot-based sampling of wildlife populations

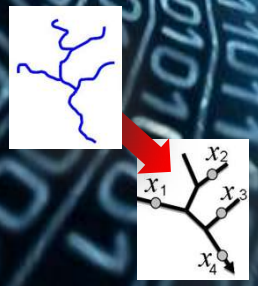
Jay M. Ver Hoef

- Terrestrial applications are common
- Theory now exists for streams



A BIG DATA Example

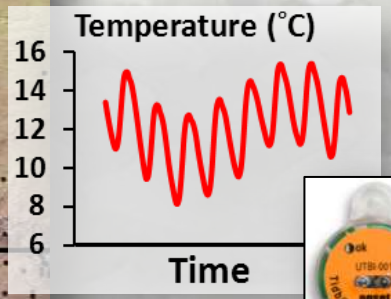


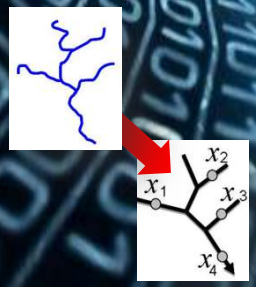


BIG DATA = BIG INFORMATION

Lots of Temperature Data Exist…

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





Lots of Temperature Data Exist…

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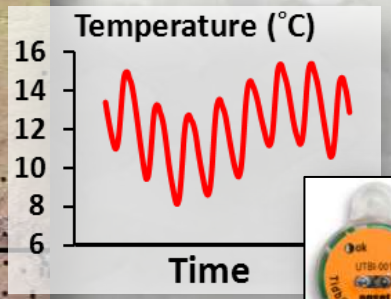
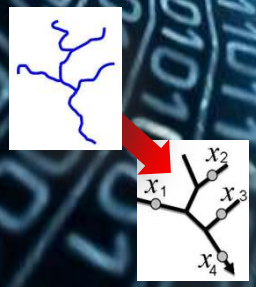
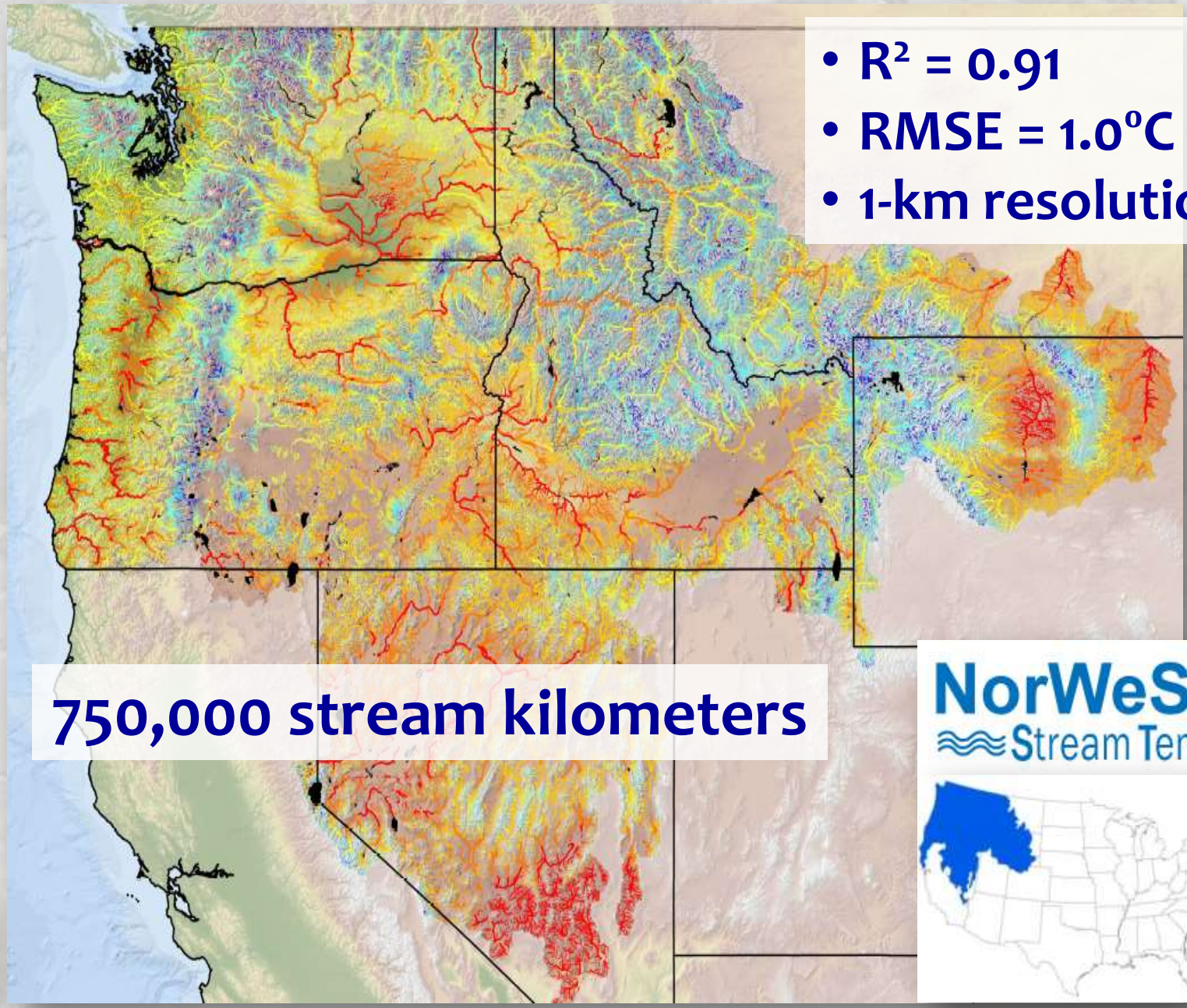


$10,000,000




It's the MOTHER LODE!
BIG DATA = BIG INFORMATION

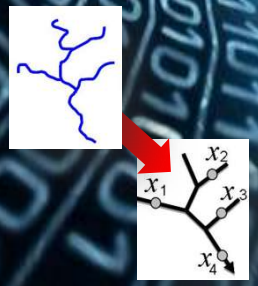
High-Resolution Stream Scenarios



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

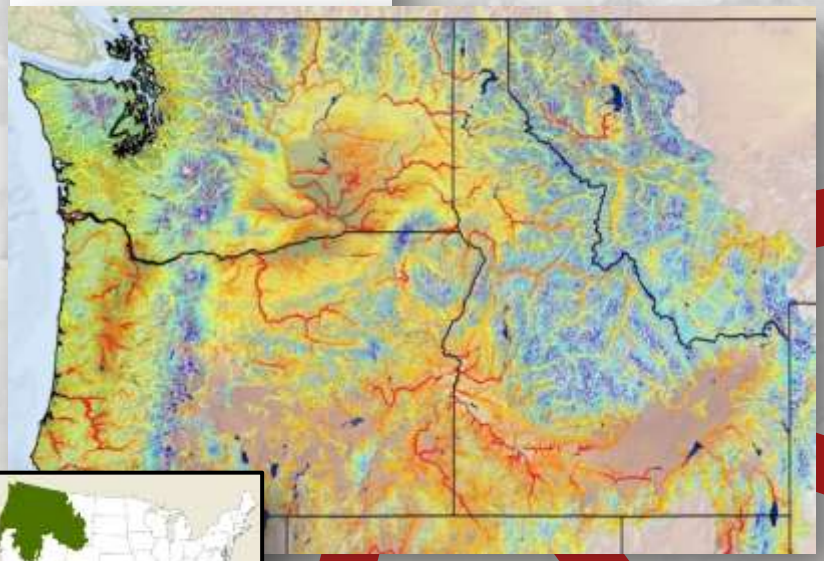
750,000 stream kilometers

NorWeST
Stream Temp



NorWeST Stream Temp

Temperature Applications

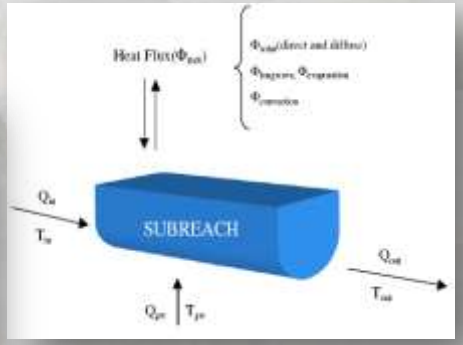


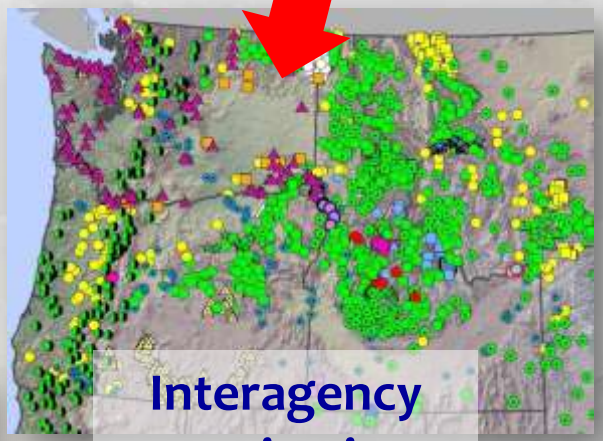
Regulatory temperature standards

Too Hot!

Too cold!

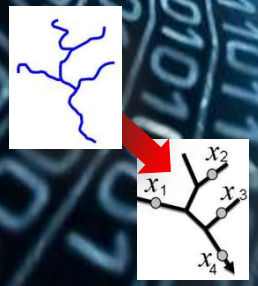
Data access accelerates temperature research



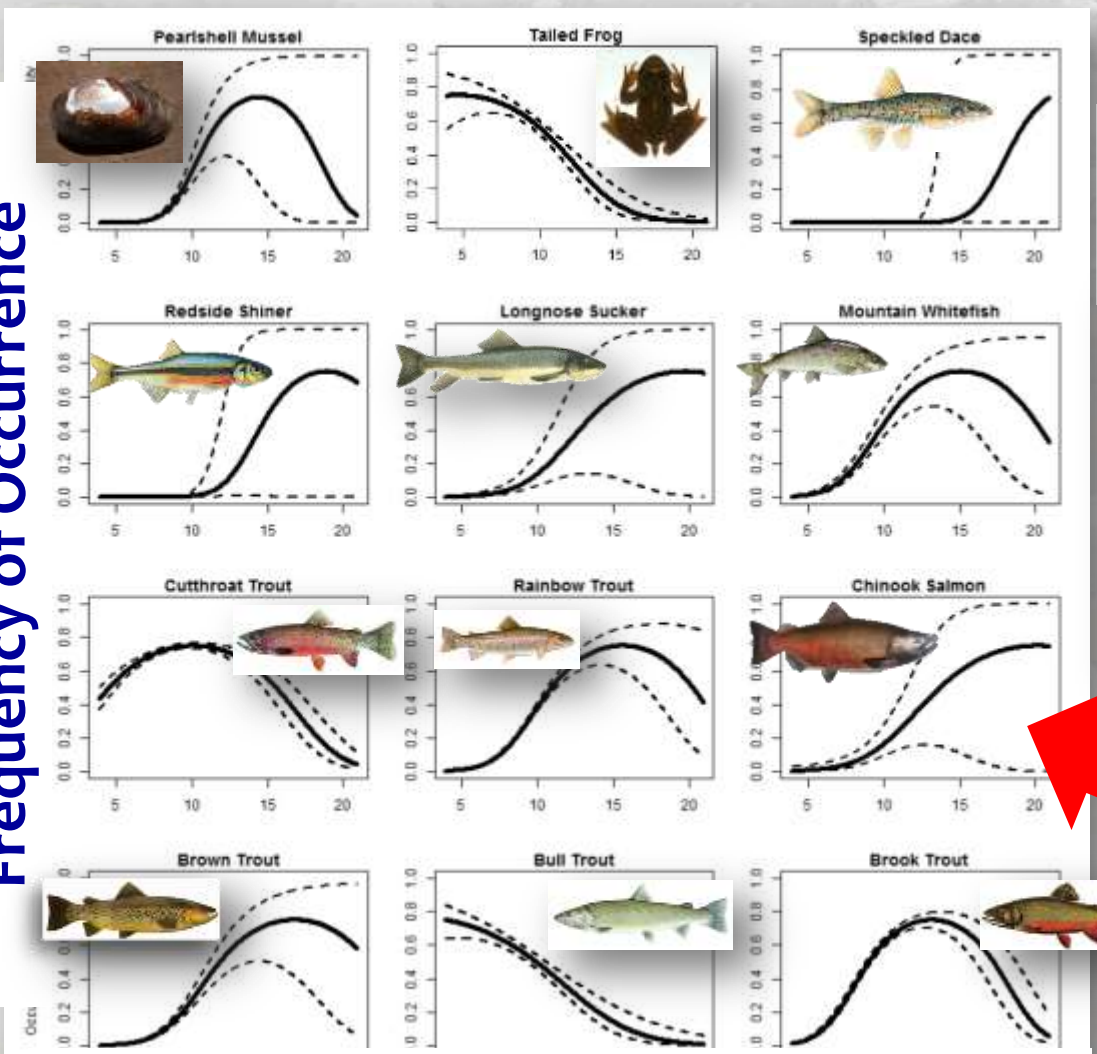


Interagency monitoring

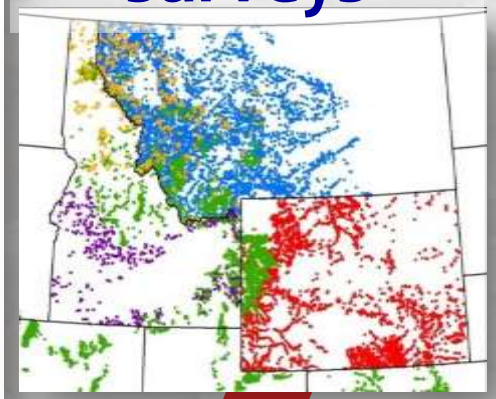
Species distribution models & climate assessments



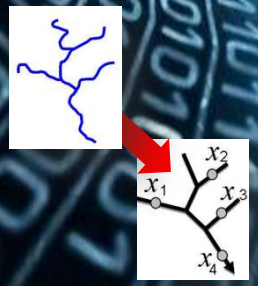
Batch Mode Thermal Criteria…



~13,000 fish surveys

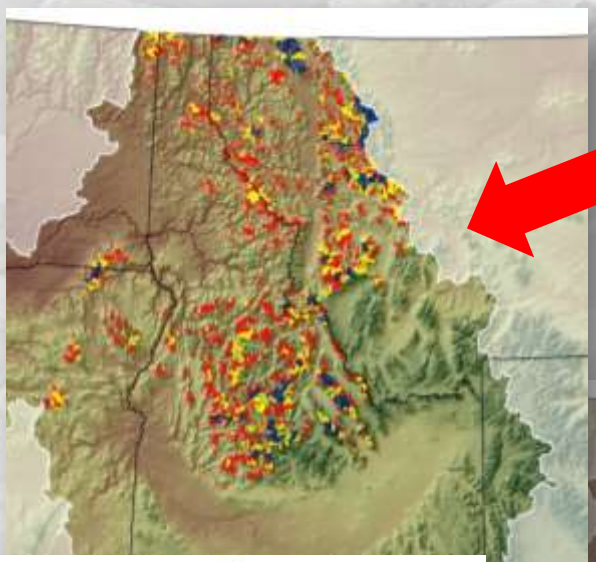


Many species!

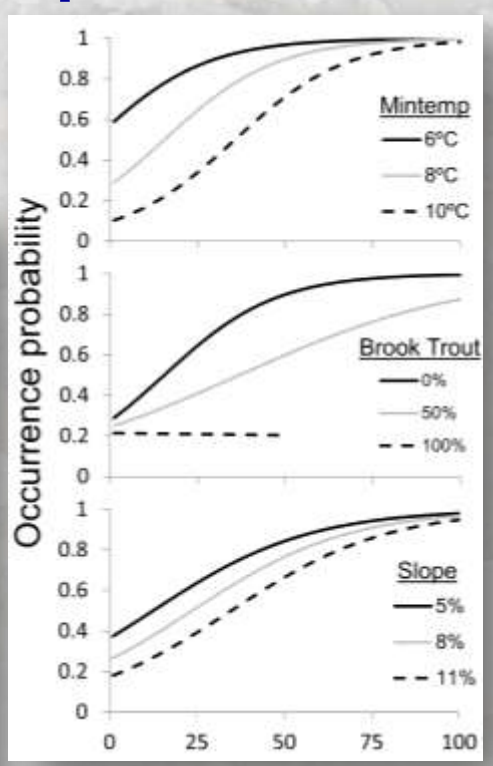


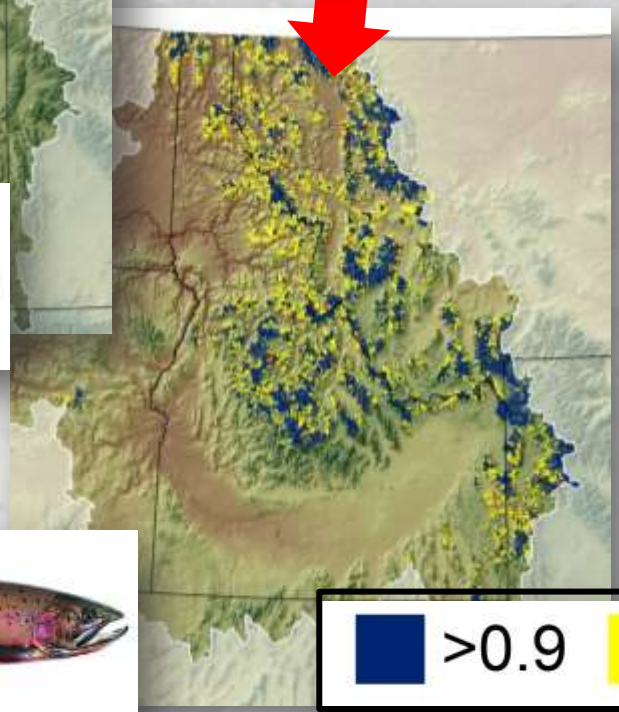
Wenger et al. *In Preparation.* Description of realized thermal niches using massive biological and temperature databases.

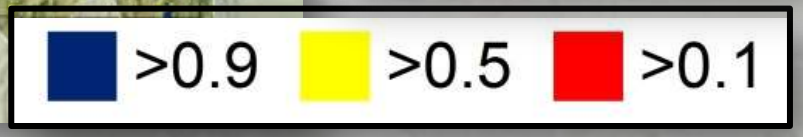
Accurate Species Distribution Models

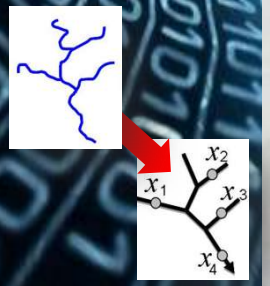


Climate refugia 2040s



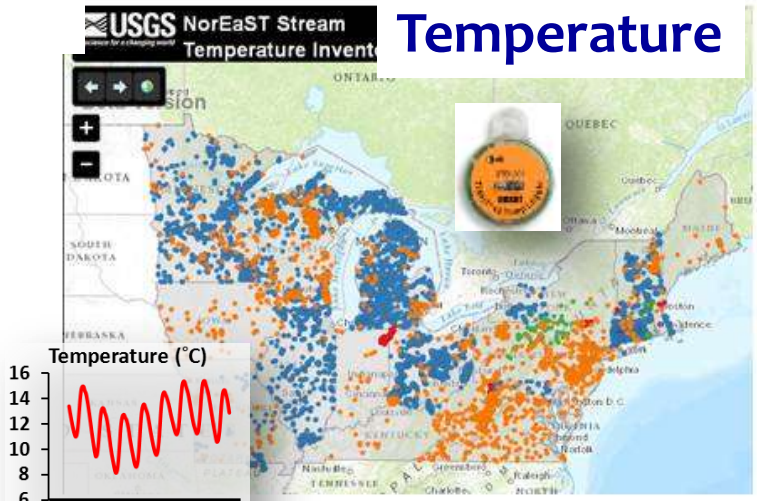


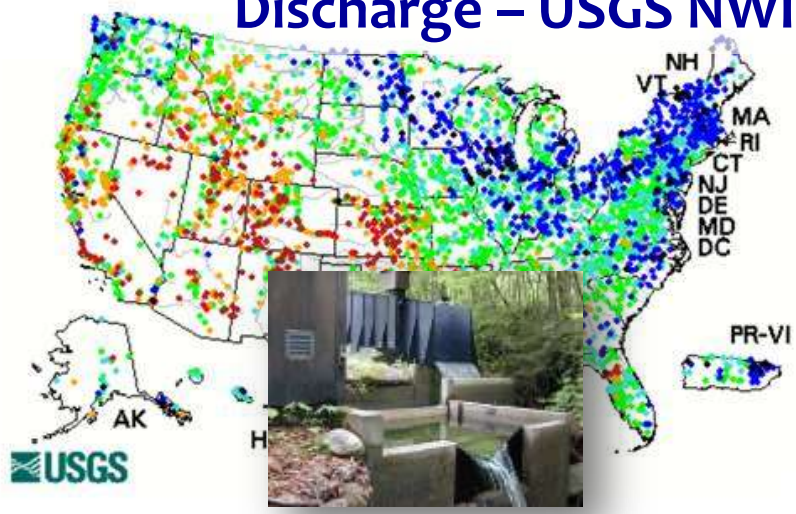


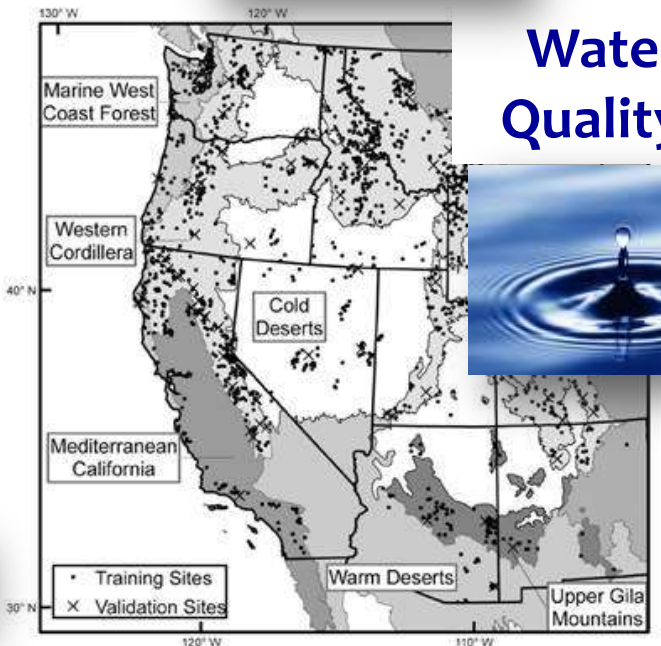


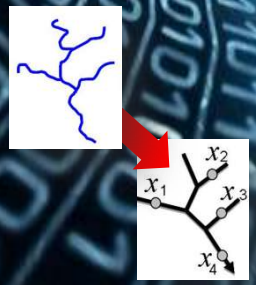
Isaak, D., M. Young, D. Nagel, D. Horan, and M. Groce. 2015. The cold-water climate shield: Delineating refugia for preserving native trout through the 21st Century. *Global Change Biology* **21** doi:10.1111/gcb.12879

Mountains of BIG DATAbases Exist or Could be Created to be Mined









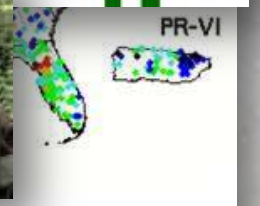
Mountains of BIG DATAbases Exist or Could be Created to be Mined

Free millions!

Temperature

Discharge – U

Free millions!



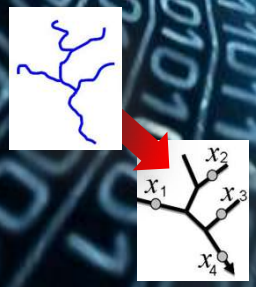
Free millions!

Water Quality

Free millions!

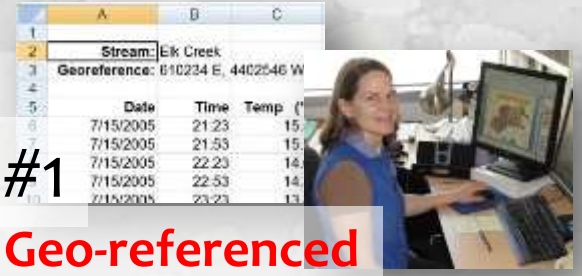
Genetic Samples

Free millions!

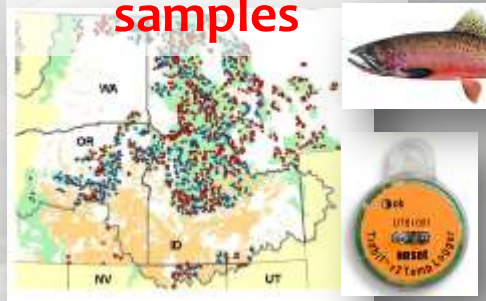


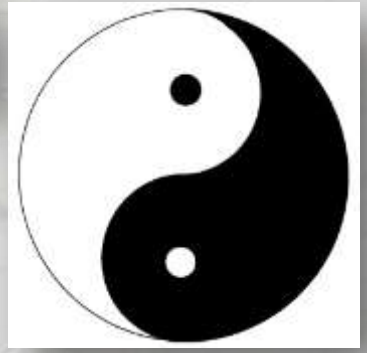
Making SSNM Analysis More Efficient

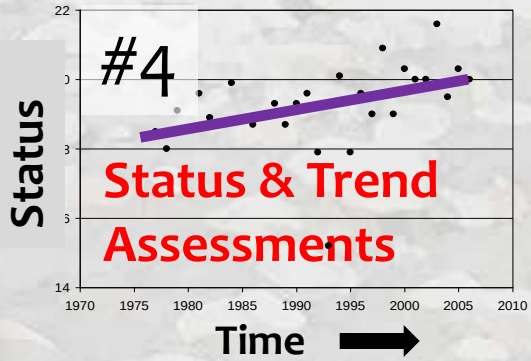
Data In → Information Out

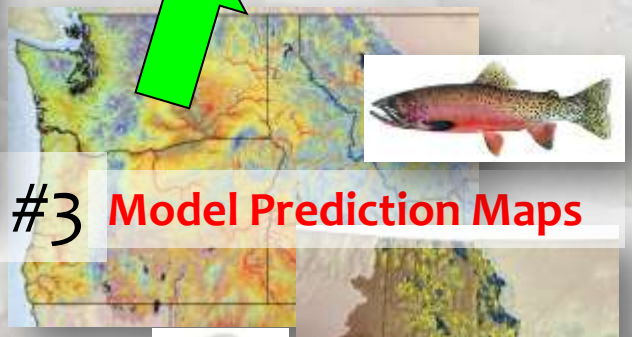


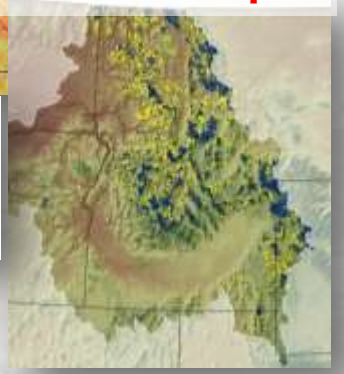
#1 Geo-referenced samples



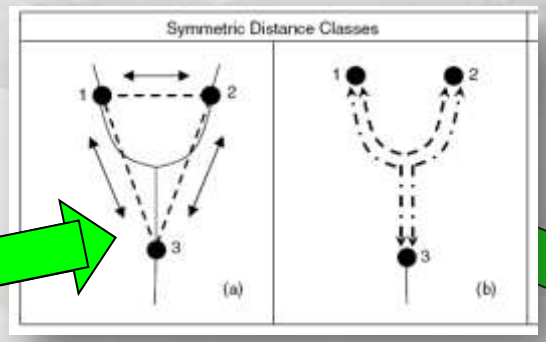




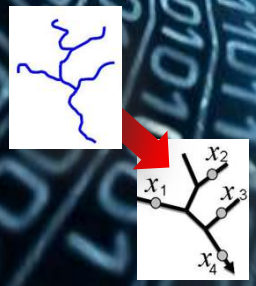




#2 Analysis



#2a More data, monitoring design



Spatial Stream Statistics Working Group

NCEAS
National Center for Ecological Analysis and Synthesis

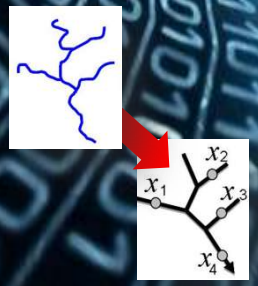
Isaak, D.J., E. Peterson, J. V. Hoef, S. Wenger, J. Falke, C. Torgersen, C. Sowder, A. Steel, M.J. Fortin, C. Jordan, A. Reusch, N. Som, P. Monestiez. 2014. Applications of spatial statistical network models to stream data. ***WIREs - Water 1***:27-294.

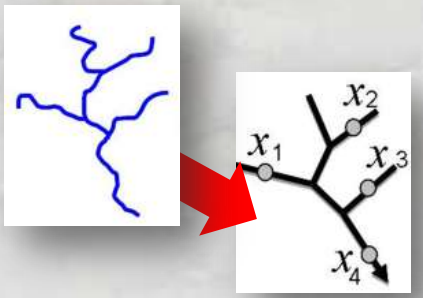
Peterson E.E. & Ver Hoef J.M. 2014. STARS: An ArcGIS toolset used to calculate the spatial information needed to fit spatial statistical models to stream network data. ***Journal of Statistical Software*** 56(2):1-17.

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.

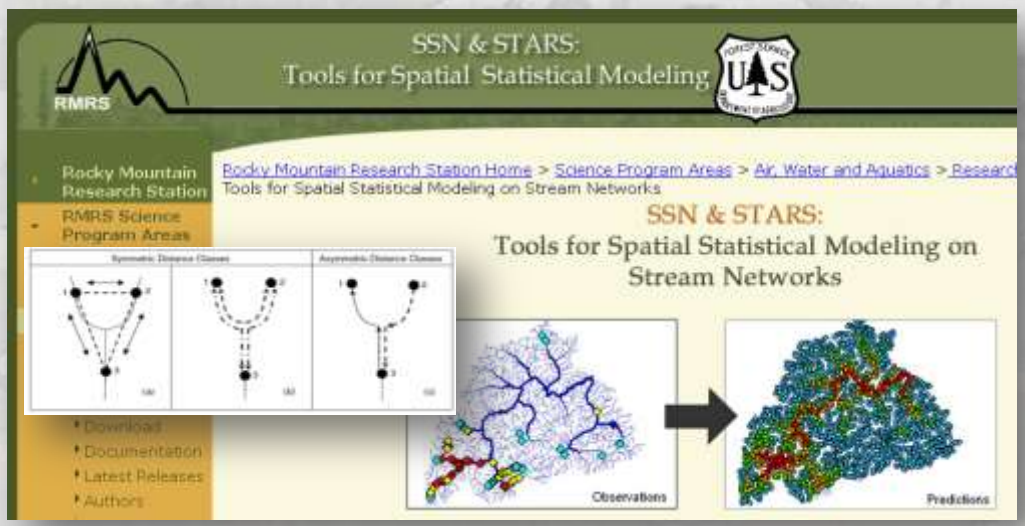
Som N.A., Monestiez P., Zimmerman D.L., Ver Hoef J.M. & Peterson E.E. In Press. Spatial sampling on streams: Principles for inference on aquatic networks. ***Environmetrics*** x:xxx.

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.



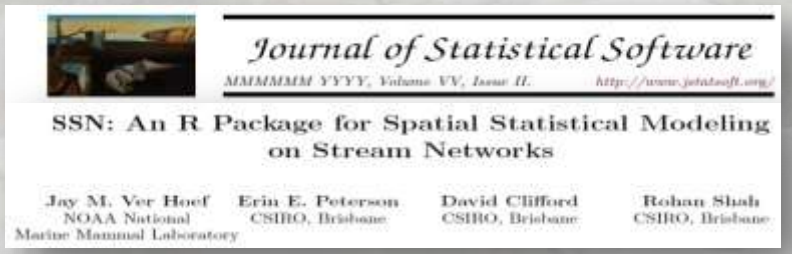


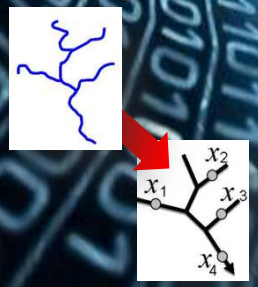
SSN/STARS Website – Free Software



Spatial Stream Networks (SSN) Package for R

- **Tutorials**
- **Example Datasets**
- **Documentation**

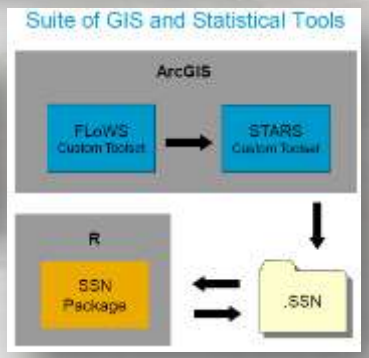




A Moving Average Approach for Spatial Statistical Models of Stream Networks

Jay M. VER HOEF and Erin E. PETERSON

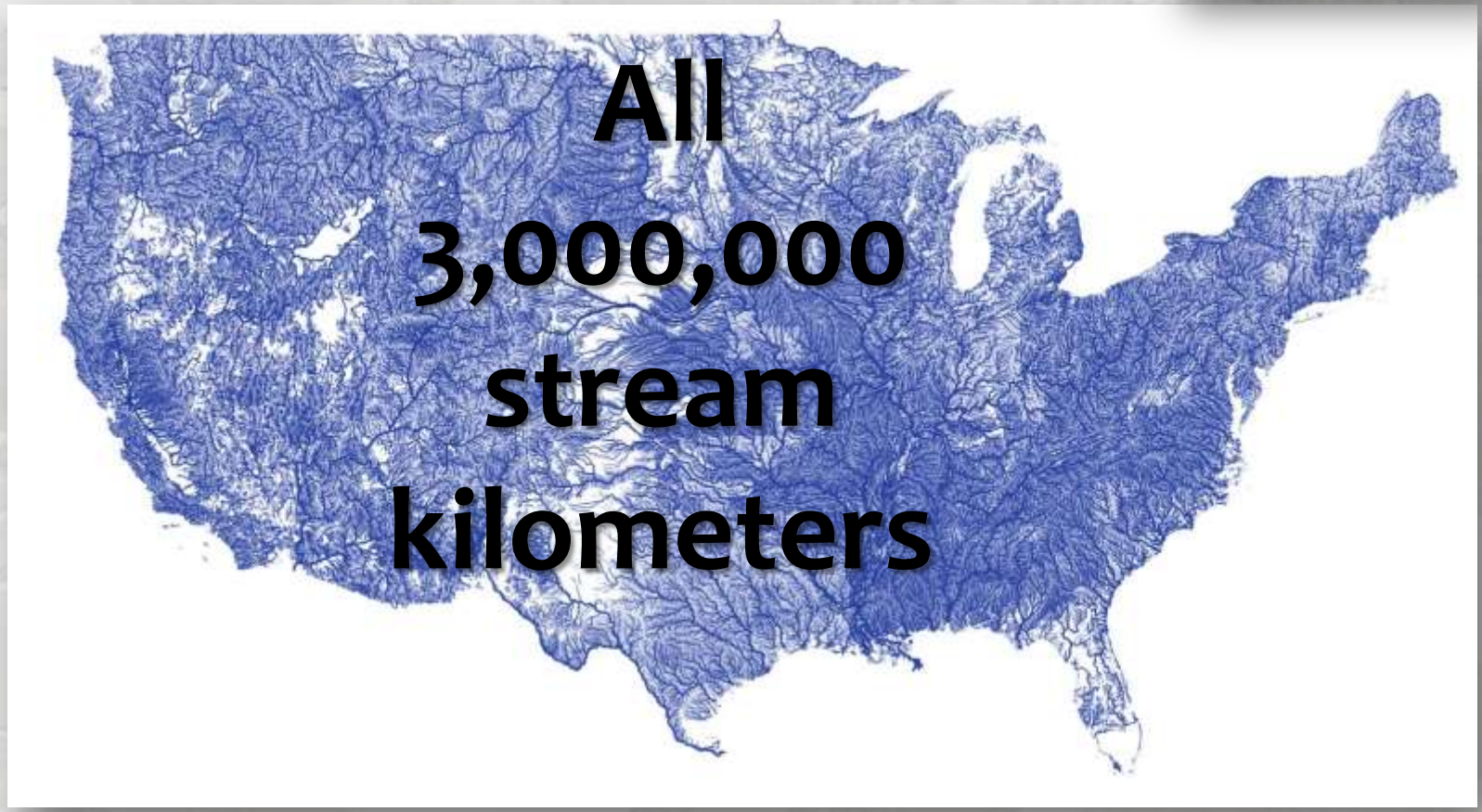
STARS: An ArcGIS toolset used to calculate the spatial data needed to fit spatial statistical models to stream network data

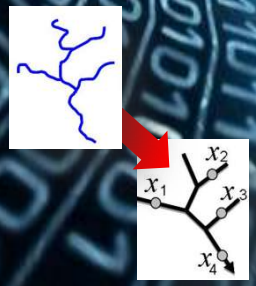


NHDPlus Digital Stream Layer

Nationally consistent geospatial database

Website: http://www.horizon-systems.com/nhdplus/

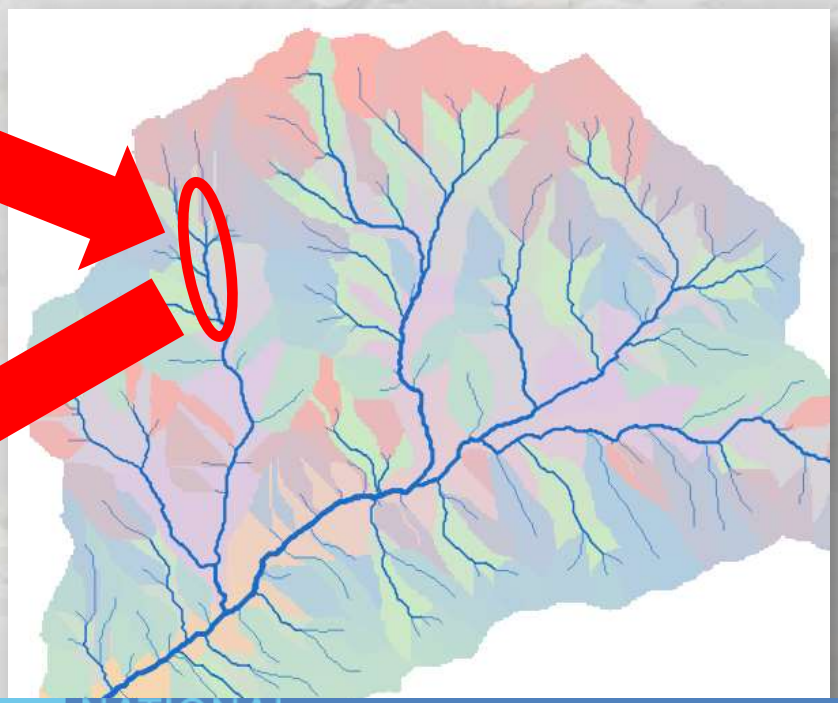




Cooter et al. 2010. A nationally consistent NHDPlus framework for identifying interstate waters: Implications for integrated assessments and interjurisdictional TMDLs. *Environmental Management* **46**:510-524.

NHDPlus Digital Stream Layer

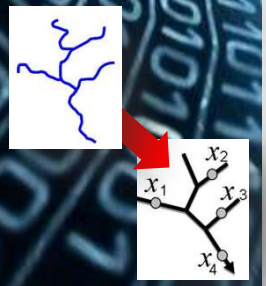
Nationally consistent geospatial database



Reach Descriptors:

- Elevation
- Slope
- %Landuse
- Precipitation

100's more…



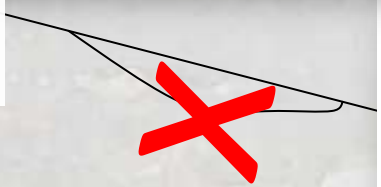
Wang et al. 2011. A Hierarchical Spatial Framework and Database for the National River Fish Habitat Condition Assessment. *Fisheries* **36**:436-449.

Conditioning NHDPlus Streams for SSNMs

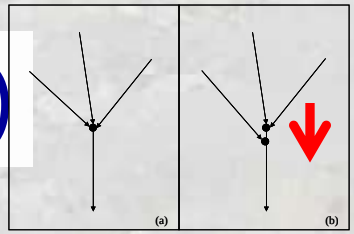
STARS Preprocessing:

1) Remove braided sections
2) 3-Confluence node adjustments
3) Create prediction points
4) Back-compatibility with NHDPlus

1)



2)



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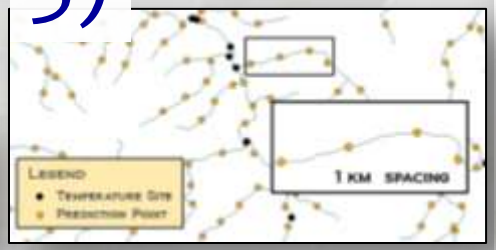
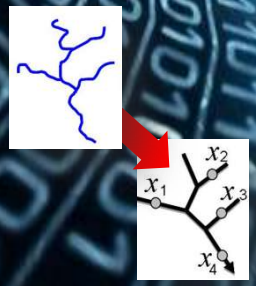
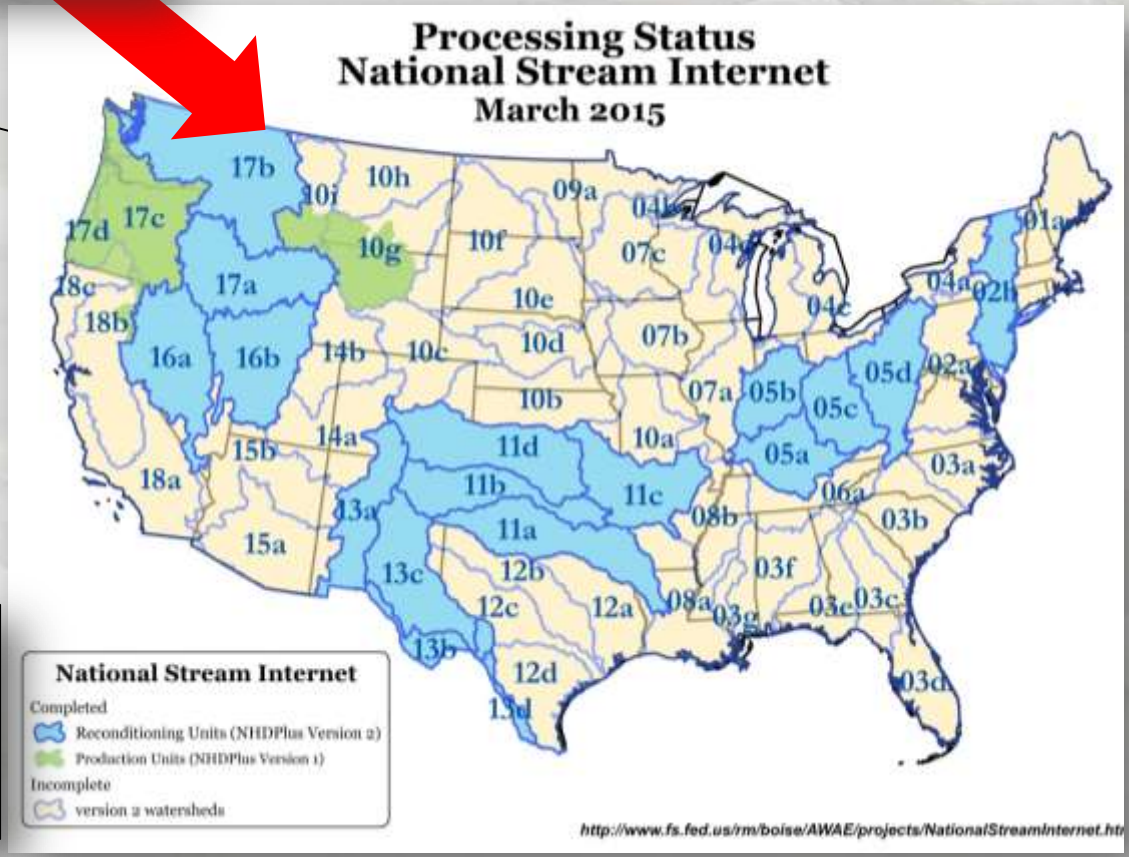
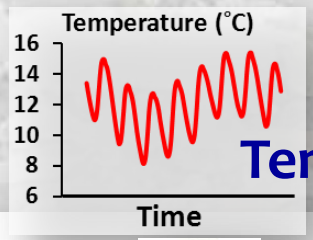






Develop a Database & Do It!

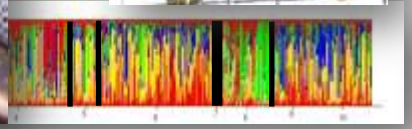
Distribution & abundance



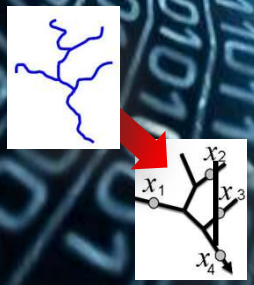
Stream Temperature

Anywhere!

Genetic Attributes



Water Quality Parameters



User Community is Growing Rapidly…

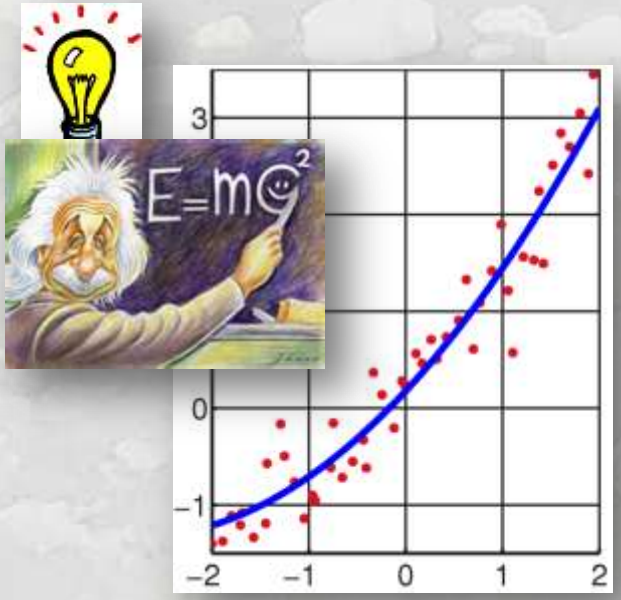
>20,000 Visits to SSN/STARS website in first 2.5 years

>600 software downloads

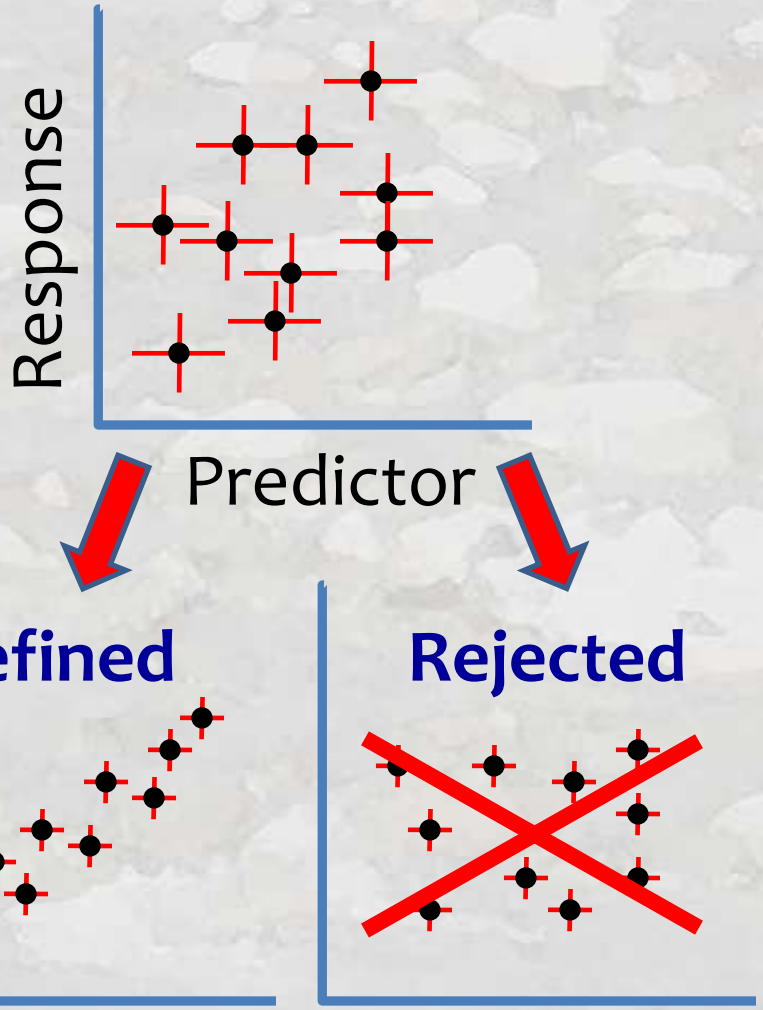
Locations of visits to SSN/STARS website in last month

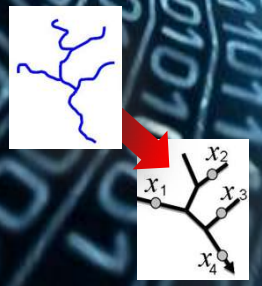
A New Era of Better Prediction & Understanding for Stream Things…

New relationships described



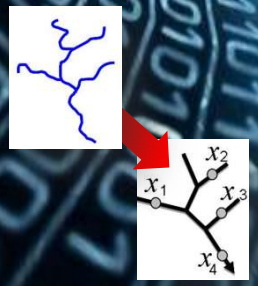
Old relationships tested





Tools for Information Creation…

Better information =
Better Conservation
& Management



stream

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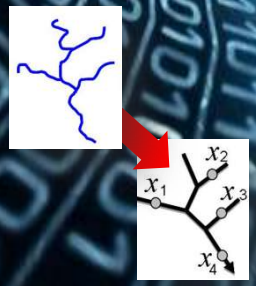

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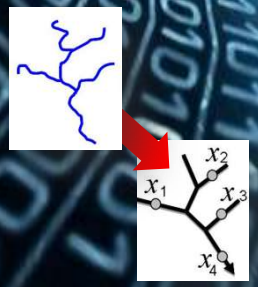

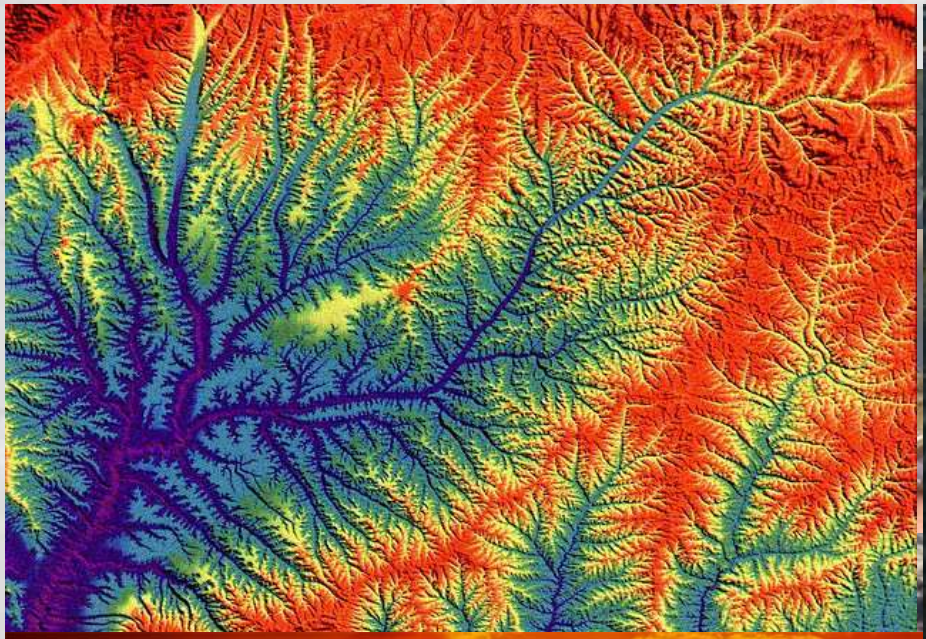

The End