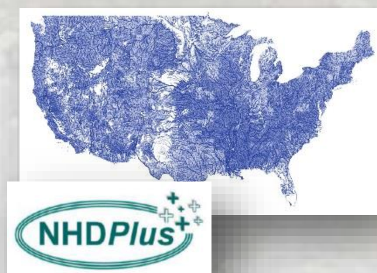
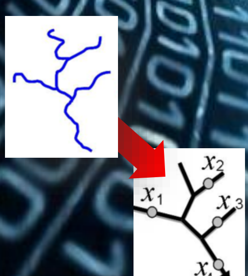
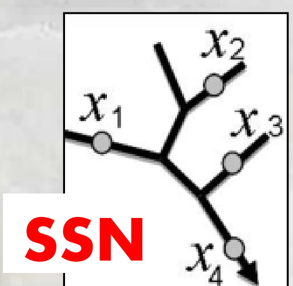
How Many Fish Live in that Stream or River Network? A Scalable Population Estimator Using SSN Models, Fish Density Datasets, and National Geospatial Database Frameworks

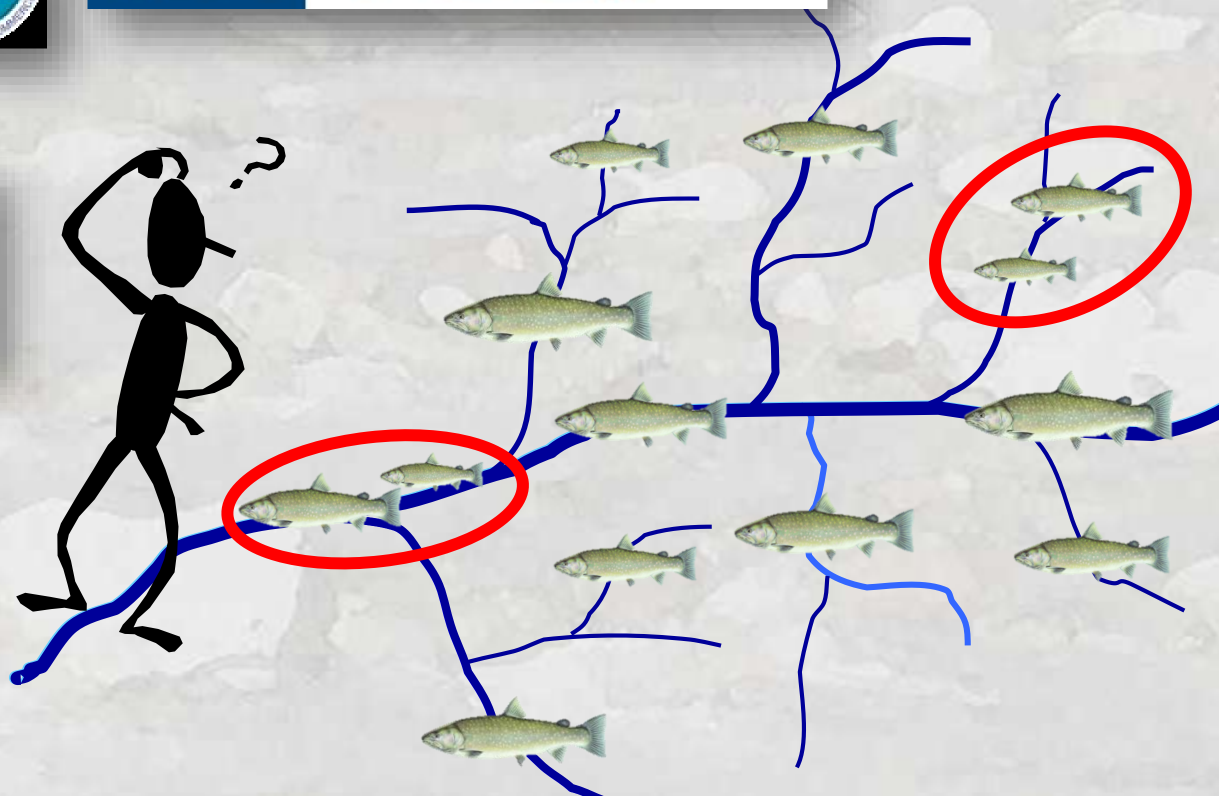
Dan Isaak, Jay Ver Hoef[1], Erin Peterson[2], Dona Horan, Dave Nagel

Queensland University of Technology









Local Population Methods

Depletion-removal (Morin 1951; Zippin 1958)

THE REMOVAL METHOD OF POPULATION ESTIMATION[1]

Calvin Zippin

Mark-recapture (Lincoln 1930; Peterson 1896)

Direct observation

United States Department of Agriculture

Forest Service

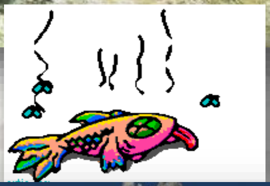
Intermountain Research Station

General Technical Report INT-GTR-307

July 1994

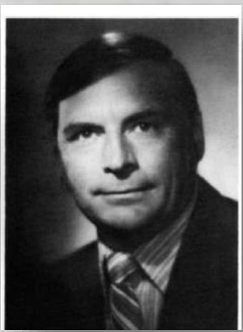
Underwater Methods for Study of Salmonids in the Intermountain West

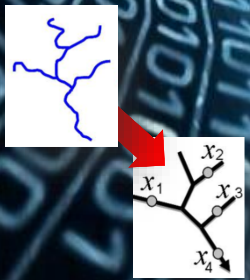
Russell F. Thurow



Blow em' up & count (Platts 1979)

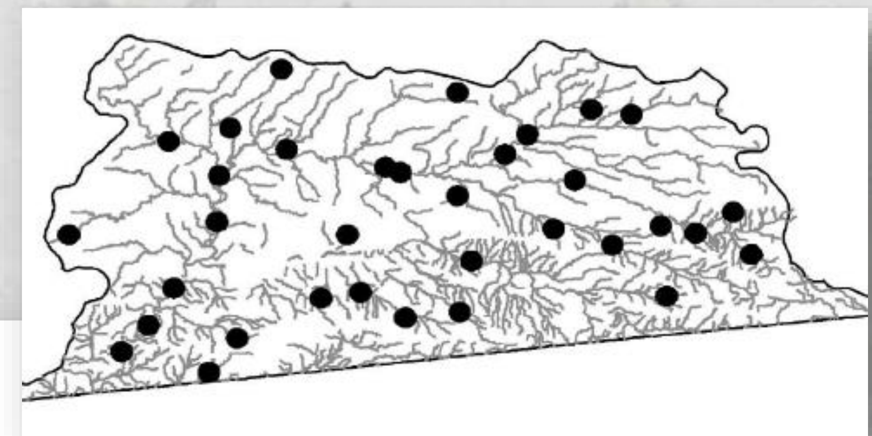
RELATIONSHIPS AMONG STREAM ORDER, FISH POPULATIONS, AND AQUATIC GEOMORPHOLOGY IN AN IDAHO RIVER DRAINAGE





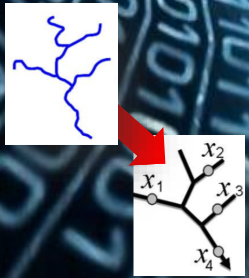
Large-Scale Population Methods:

Random Sampling Estimators (GRTS, systematic, stratified, etc.)



$$\text{sample mean} = \bar{y} = \hat{\mu} = \frac{y_1 + y_2 + \ldots + y_n}{n}$$

$$\text{estimate for population total} = \hat{\tau} = N \times \bar{y} \text{ (expansion estimator)}$$



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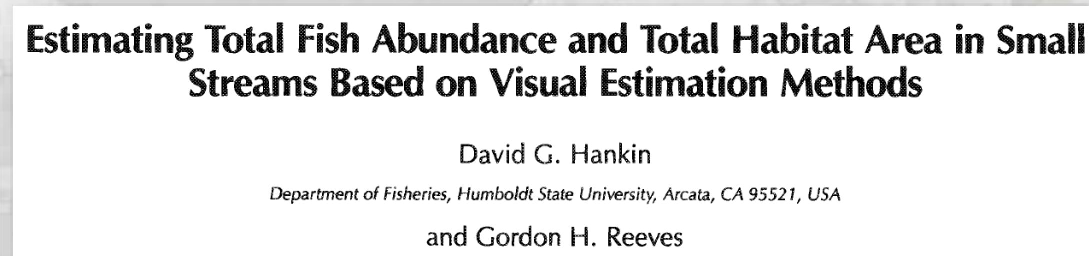
Random Sampling Estimators (GRTS, systematic, stratified, etc.)



Estimating Total Fish Abundance and Total Habitat Area in Small Streams Based on Visual Estimation Methods

David G. Hankin

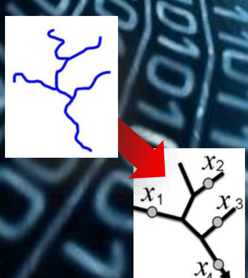
Department of Fisheries, Humboldt State University, Arcata, CA 95521, USA

and Gordon H. Reeves

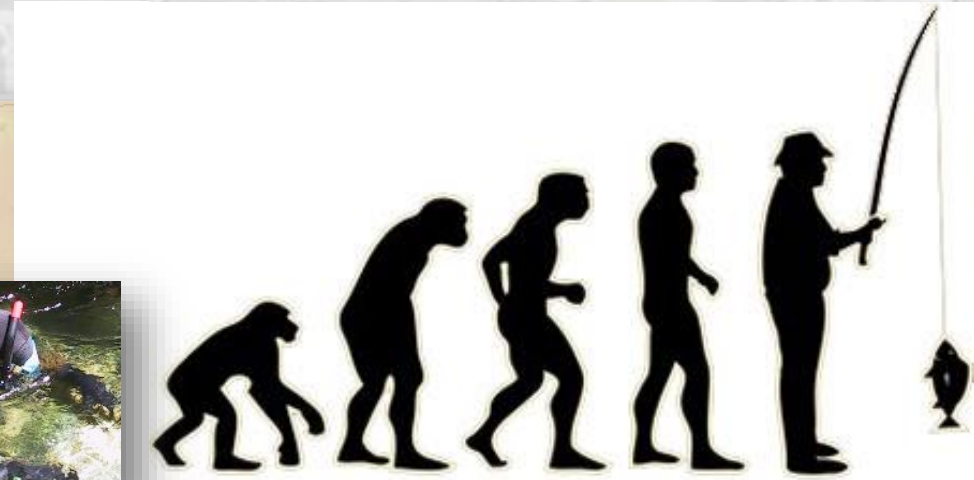
"Riverscape" snorkeling approach
Studies by Torgersen & colleagues

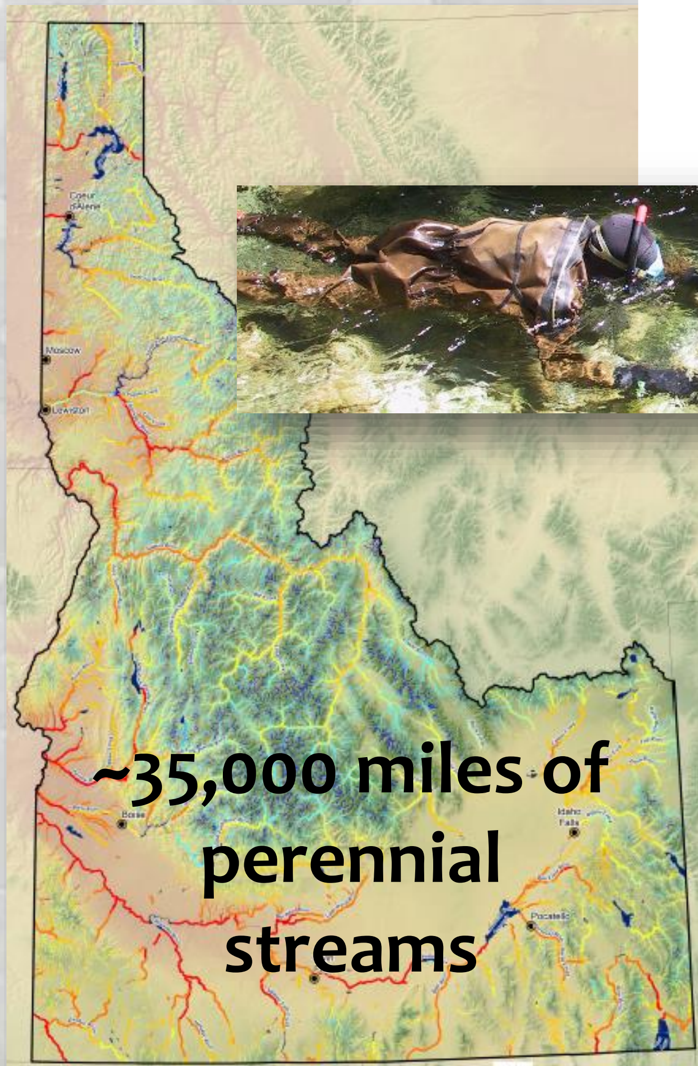
Same with electrofishing samples (or combinations of gear types):

- Hilderbrand 2000 (cutthroat trout)
- Cook et al. 2011 (cutthroat trout)
- High et al. 2008 (bull trout)
- Korman et al. 2016 (rainbow trout)



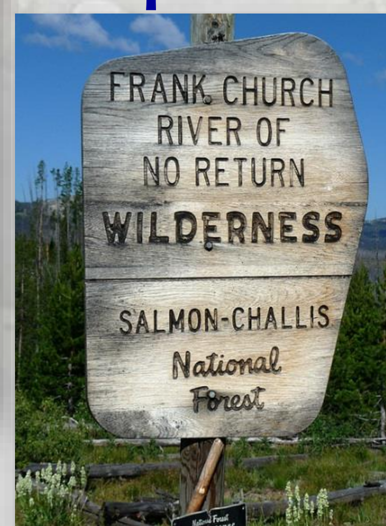
Problems: 1) Crawling forever is not a pleasant option

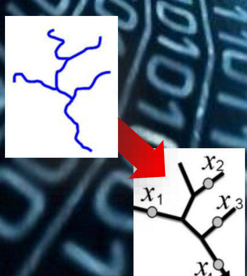




~35,000 miles of perennial streams

2) Random sampling is expensive &/or often impossible

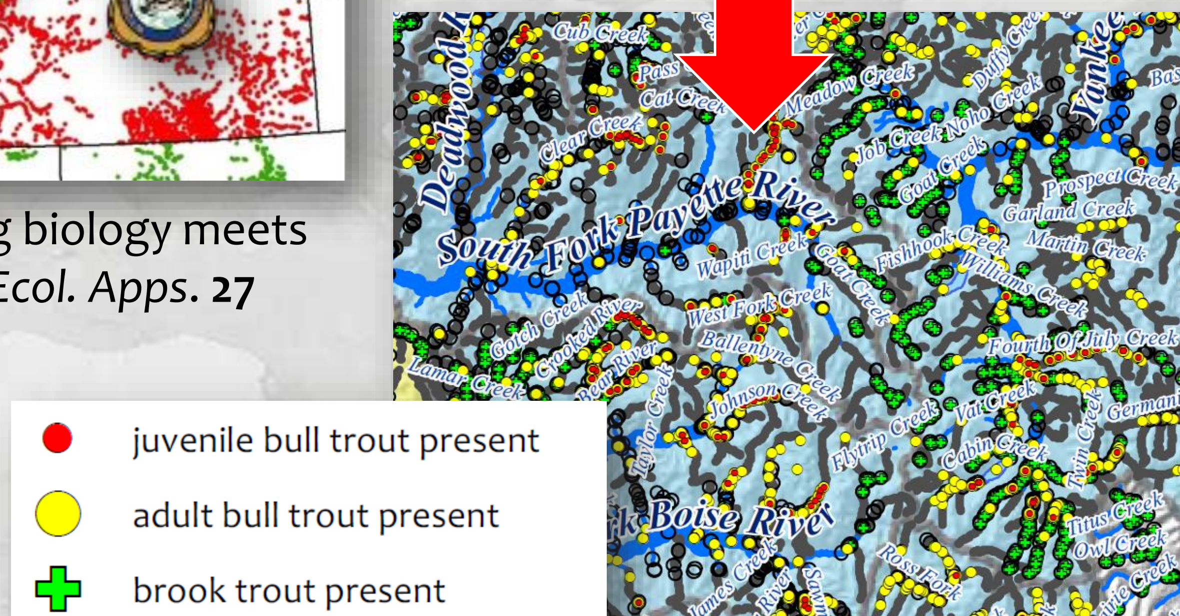


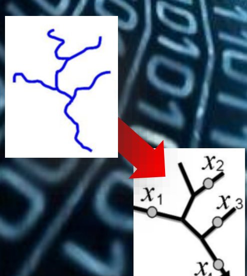


Problem 3: Discounts huge amounts of data that are nonrandomly located (millions US$)

>20,000 fish sample sites

Isaak et al. 2017. Big biology meets microclimatology. *Ecol. Apps*. **27**

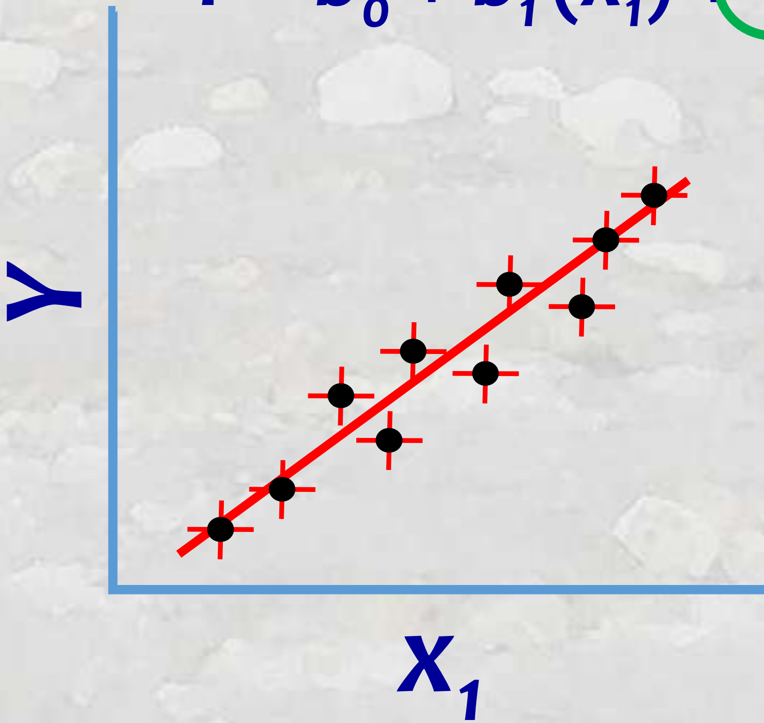


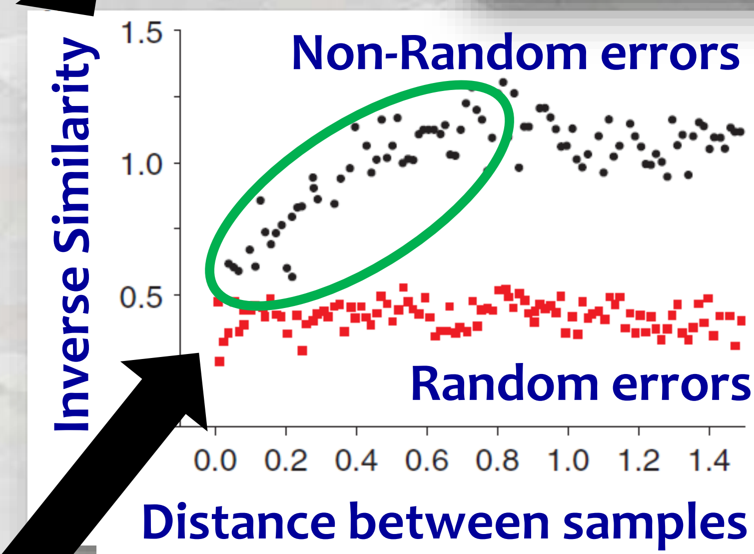


Spatial Linear Models for Non-Random Data

Cressie. 1993. Statistics for spatial data. John Wiley & Sons.

$$Y = b_0 + b_1(x_1) + €$$





AutoCovariance Function Models Spatial Structure in Residual Errors

Spatial-Stream-Network (SSN) Models for Non-Random Data on Networks

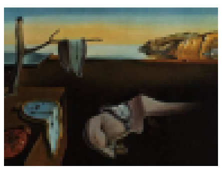
Environ Ecol Stat (2006) 13:449–464
DOI 10.1007/s10651-006-0022-8

ORIGINAL ARTICLE

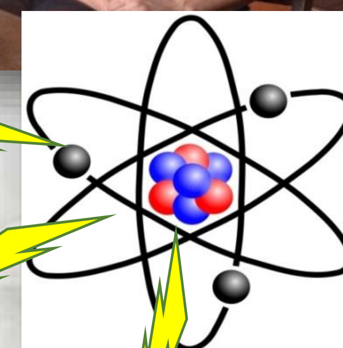
Spatial statistical models that use flow and stream distance

Jay M. Ver Hoef · Erin Peterson · David Theobald

2006



Journal of Statistical Software
January 2014, Volume 56, Issue 3. *http://www.jstatsoft.org/*

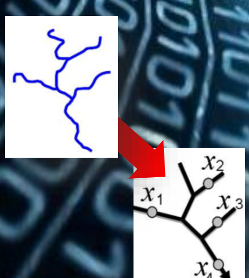


SSN: An R Package for Spatial Statistical Modeling on Stream Networks

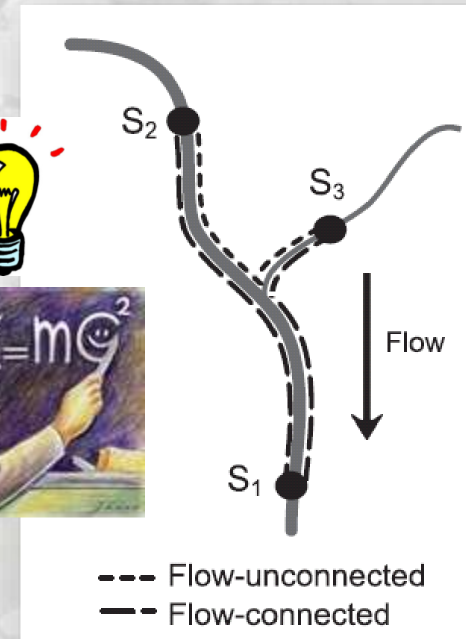
Jay M. Ver Hoef, NOAA National Marine Mammal Laboratory
Erin E. Peterson, CSIRO, Brisbane
David Clifford, CSIRO, Brisbane
Rohan Shah, CSIRO, Brisbane

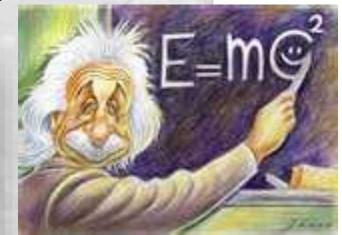
Functional Linkage of Watersheds and Streams (FLoWS)

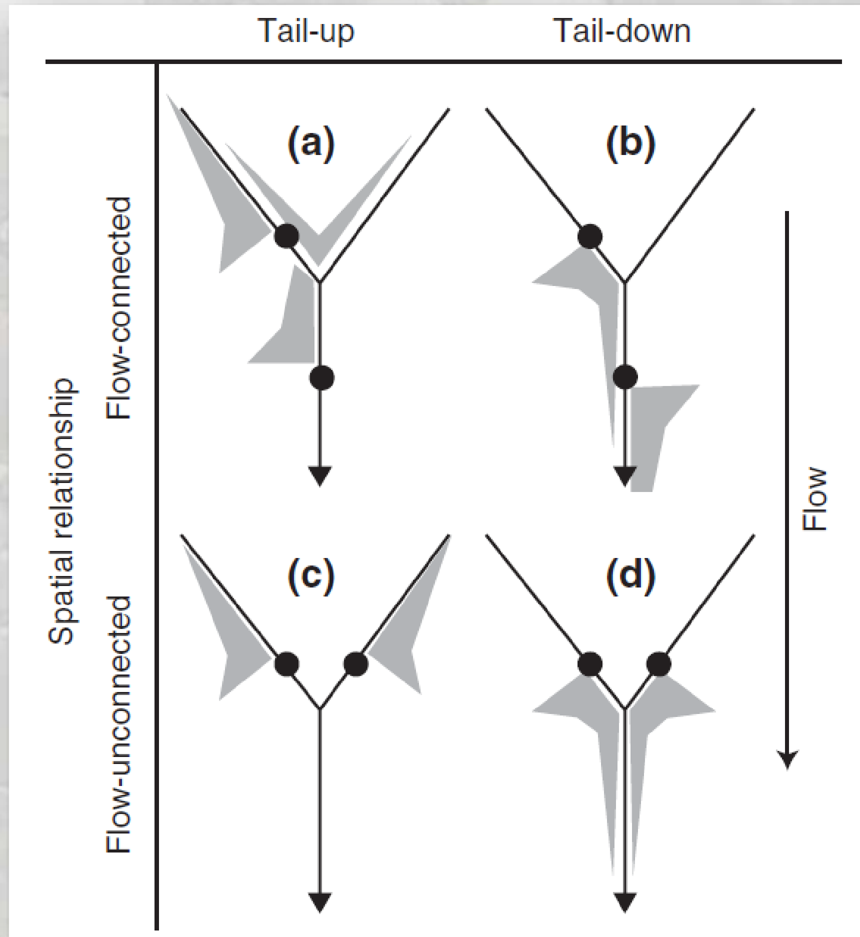
- ArcGIS Geoprocessing Toolbox written in Python v2.5 for ArcGIS v9.3
- Developed by Dr. Dave Theobald and John Norman at Colorado State

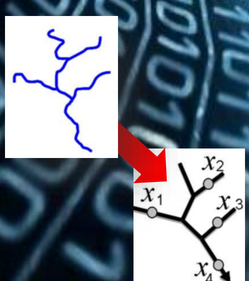


Key Innovation is Covariance Structure Based On Network Structure





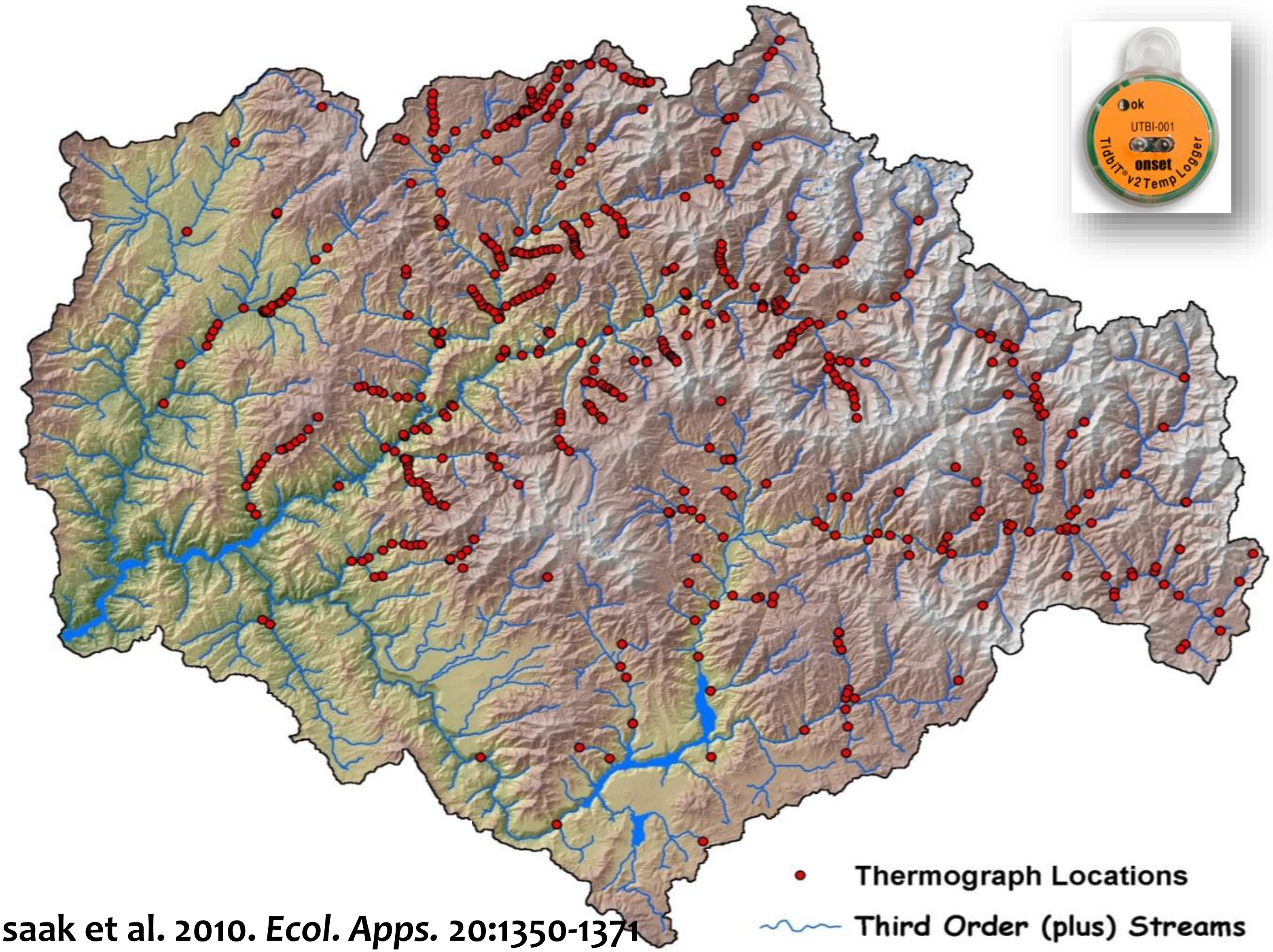


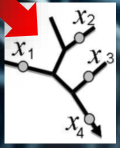


- **Models "understand" how information moves among locations**
- **Models account for spatial autocorrelation among observations**

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

Accurate Information from Non-Random Datasets With Spatially Dependent Samples





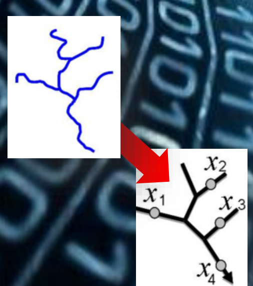
Isaak et al. 2010. *Ecol. Apps.* 20:1350-1371

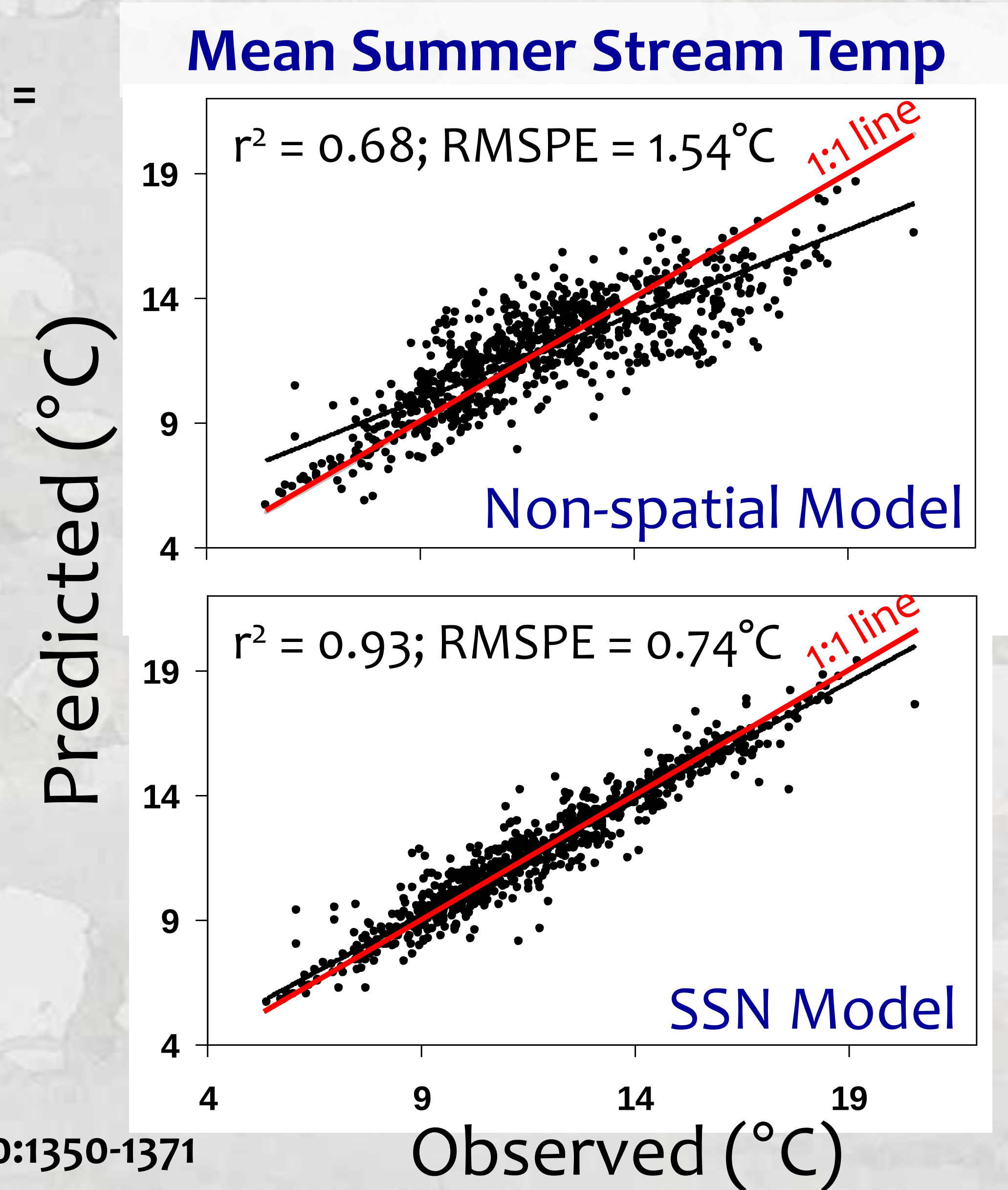
Accurate Information from Non-Random Datasets With Spatially Dependent Samples

Non-spatial Stream Temp =
– 0.0064*Elevation (m)
+ 0.0104*Radiation
+ 0.39*AirTemp (°C)
– 0.17*Flow (m³/s)

Autocorrelation affects parameter estimates

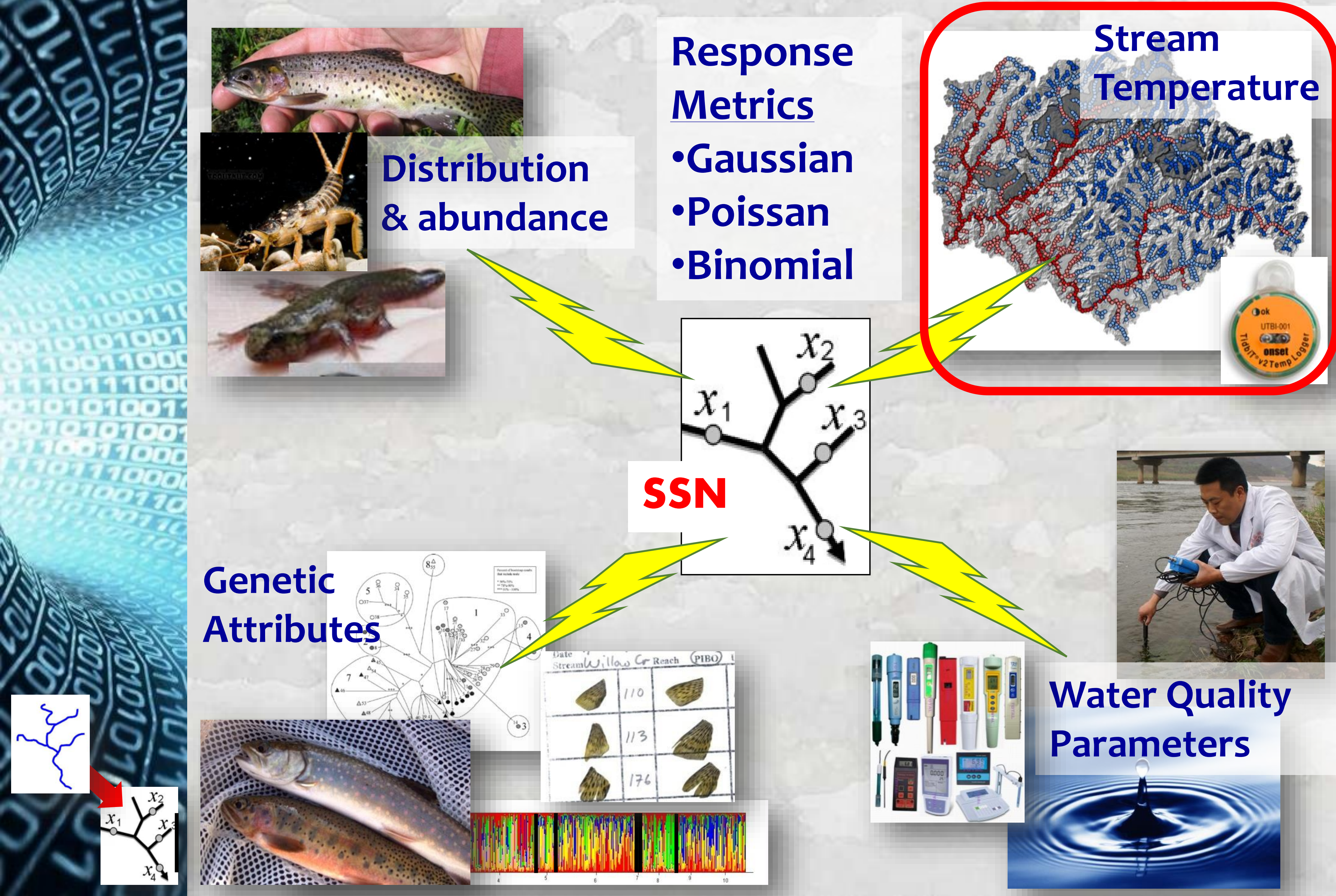
SSN Stream Temp =
– 0.0045*Elevation (m)
+ 0.0085*Radiation
+ 0.48*AirTemp (°C)
– 0.11*Flow (m³/s)





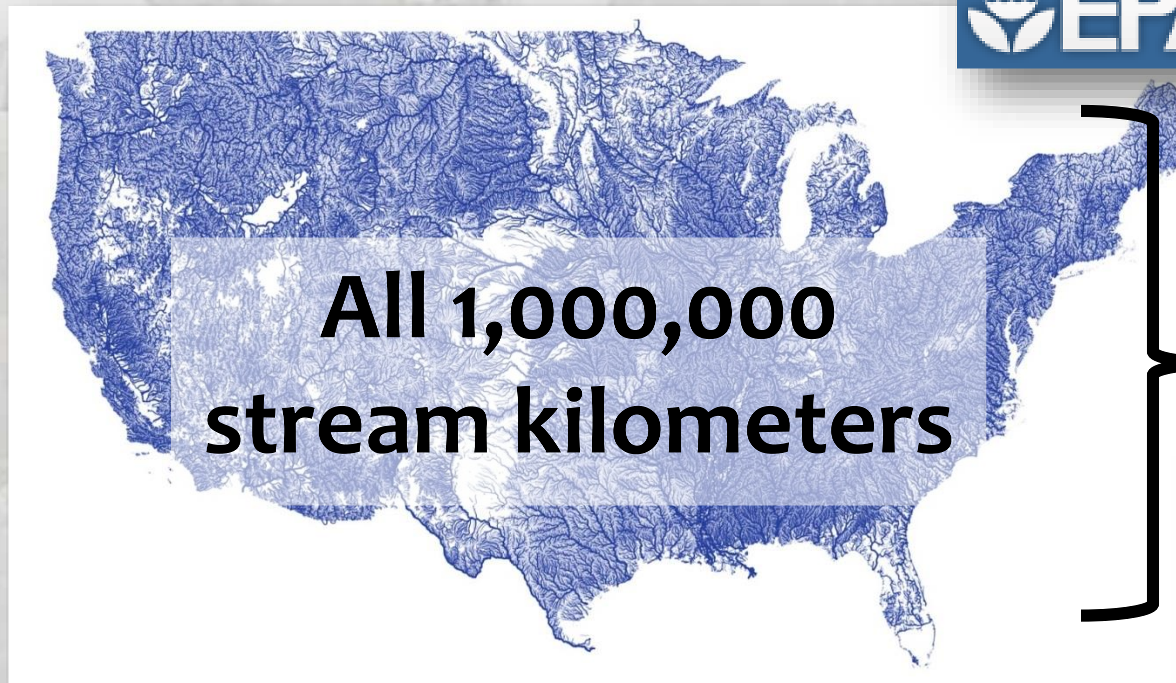
Isaak et al. 2010. ***Ecol. Apps.*** **20:1350-1371**

SSN Models are Generalizable…

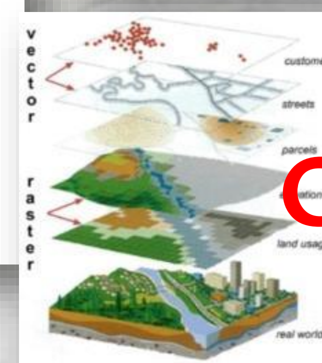


Generalizable Data Framework

National Hydrography Dataset



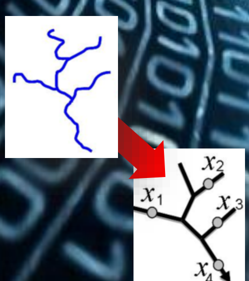
NHDPlus



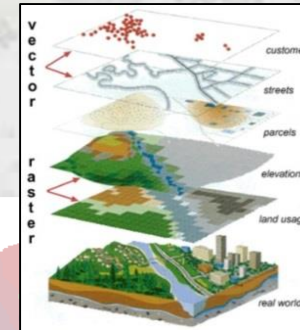
GIS

McKay et al. 2015. NHDPlus Version 2: User Guide.
Available at: ftp://ec2-54-227-241-43.compute-1.amazonaws.com/NHDplus/NHDPlusV21/Documentation/NHDPlusV2_User_Guide.pdf

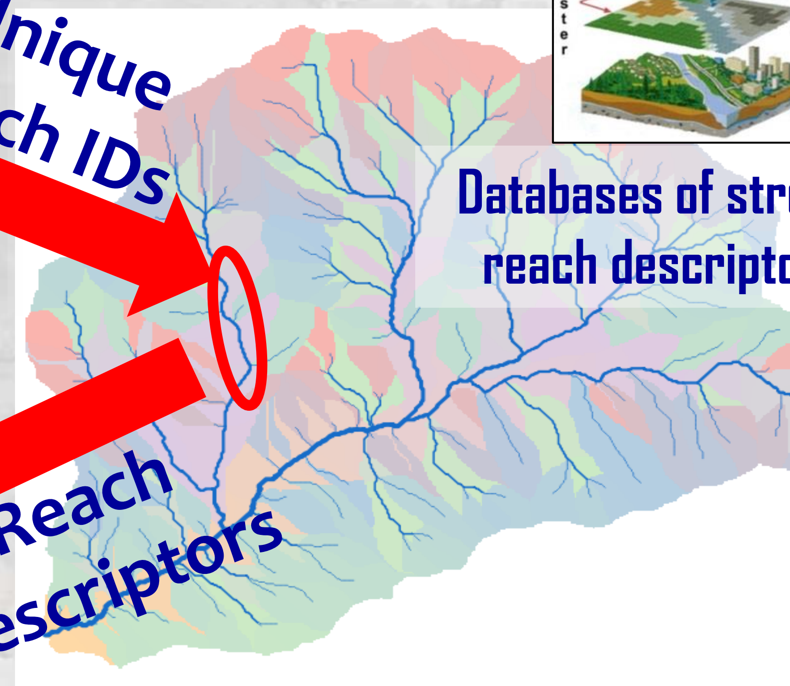
Cooter et al. 2010. A nationally consistent NHDPlus framework for identifying interstate waters: Implications for integrated assessments and interjurisdictional TMDLs. *Environmental Management* **46**:510-524.



Bonus: The "PLUS" part of NHD-Plus (Stream Reach Descriptors)



Unique reach IDs



Databases of stream reach descriptors

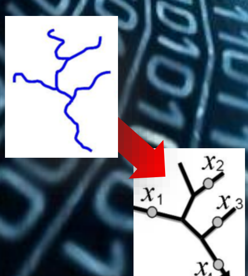
- Elevation
- Slope
- %Landuse
- Precipitation

100's more…

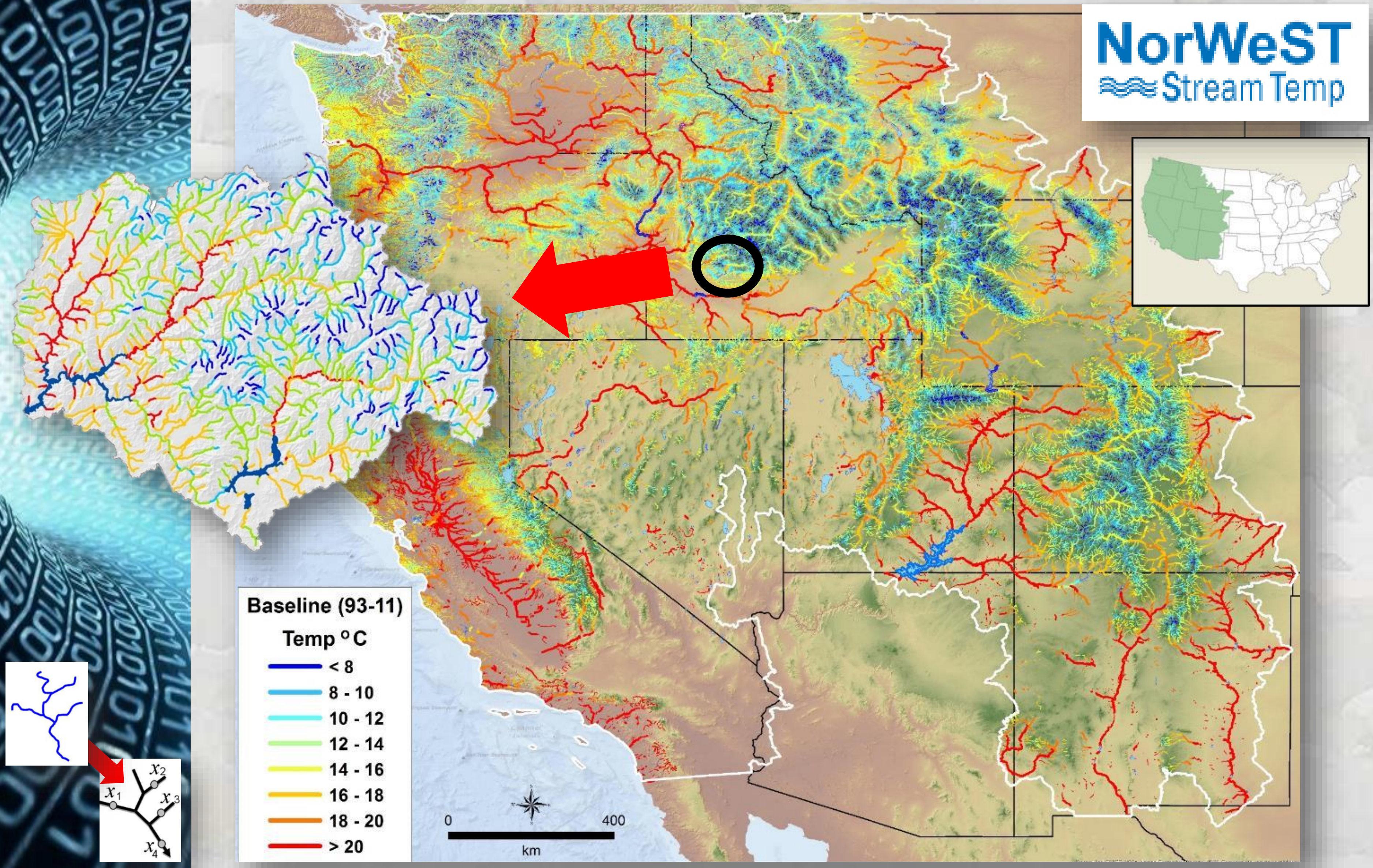
Reach descriptors

Wang et al. 2011. A hierarchical spatial framework and database for the national river fish habitat condition assessment. *Fisheries* **36**: 436-449.
Available at: https://www.researchgate.net/profile/Lizhu_Wang2

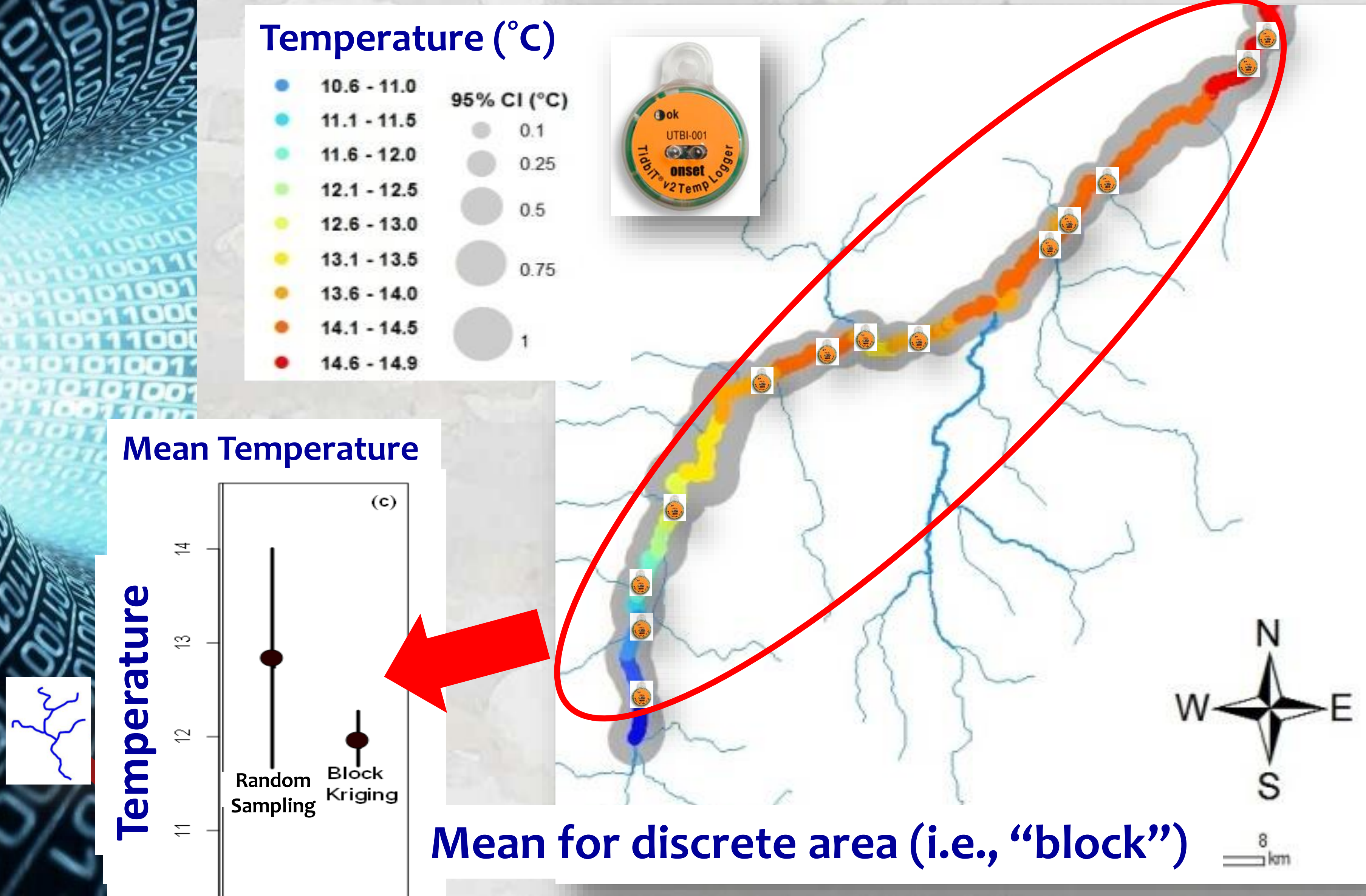
Hill et al. 2016. The stream-catchment (StreamCat) dataset: A database of watershed metrics for the conterminous USA. *The Journal of the American Water Resources Association.*
Available at: http://www2.epa.gov/national-aquatic-resource-surveys/streamcat



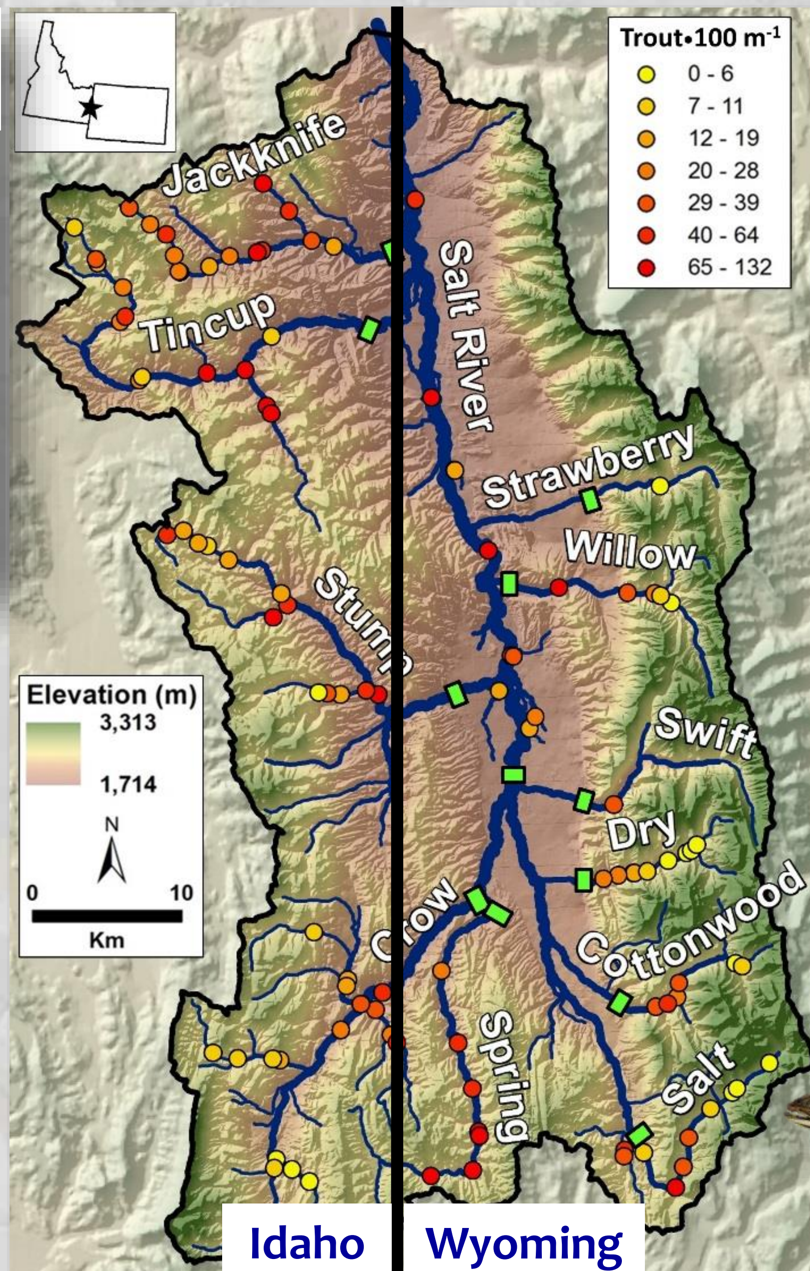
Consistent Model Predictions
In River Networks Large & Small



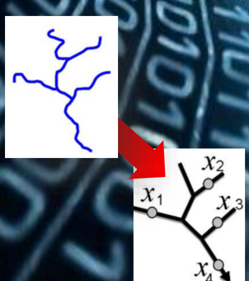
SSNs Models Represent Spatial Variation in Prediction Precision



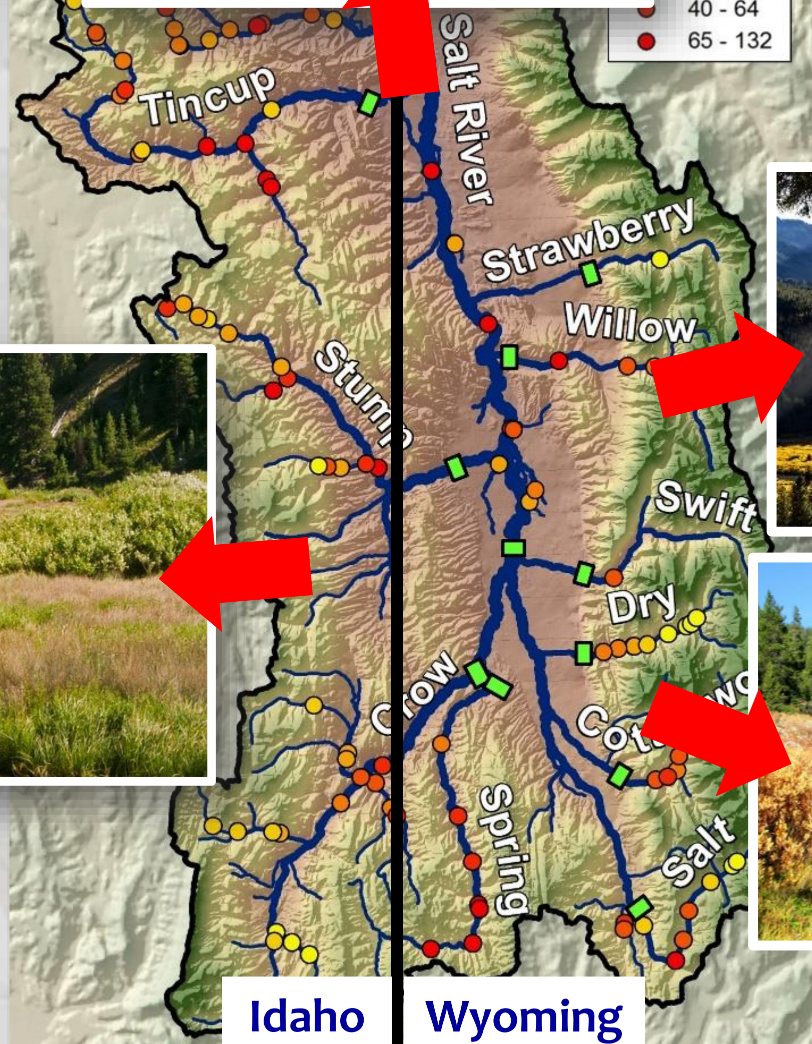
Example Salt River Fish Density Dataset

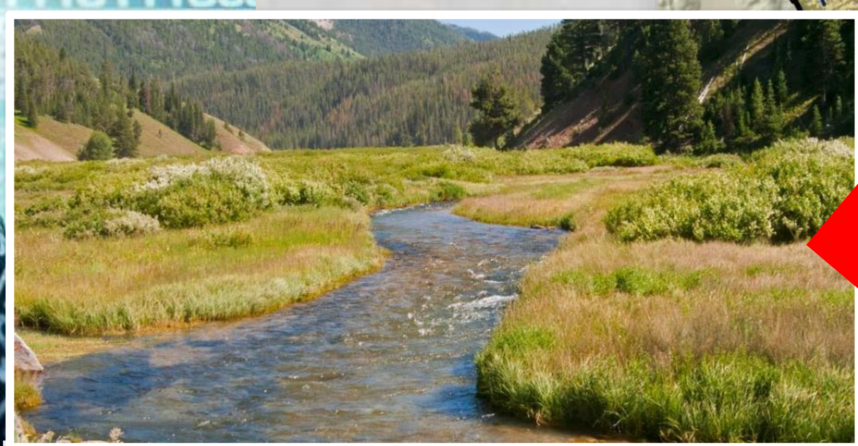


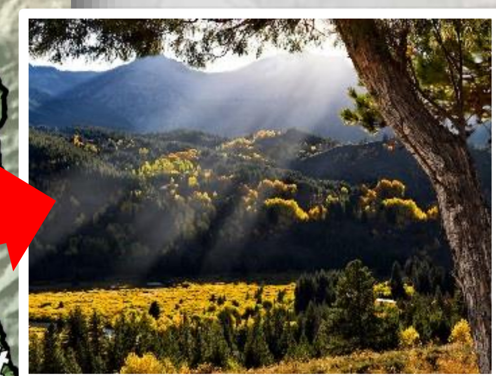
- Strong contrasts in mountain range geomorphologies & streams
- 735 km network of fish-bearing streams
- 108 sites sampled (104 backpack electro-depletion; 4 river sites WYGF raft mark-recapture)
- ~5,000 trout handled (83% were cutthroat trout)

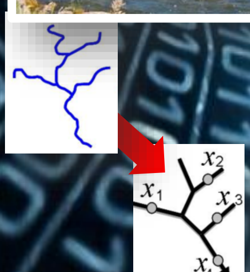


Example S ensity Dataset

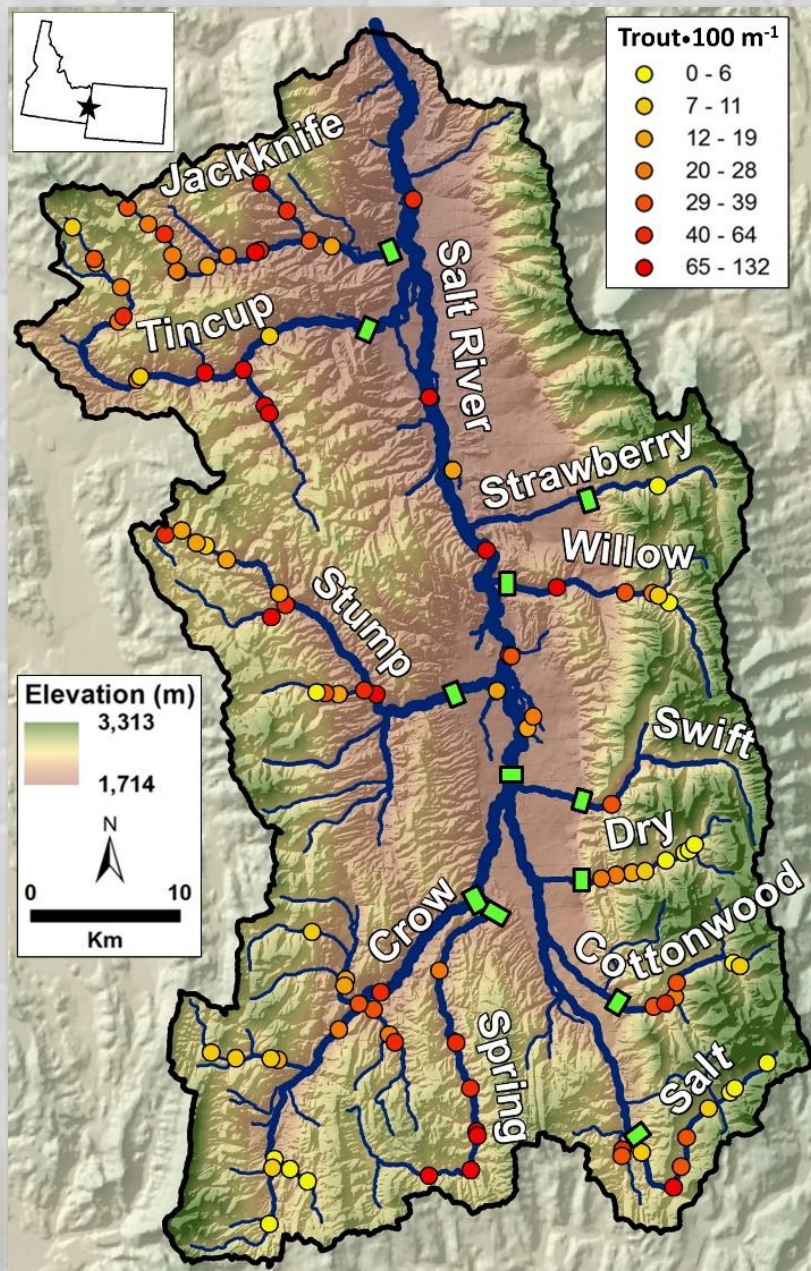




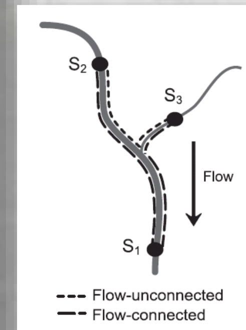




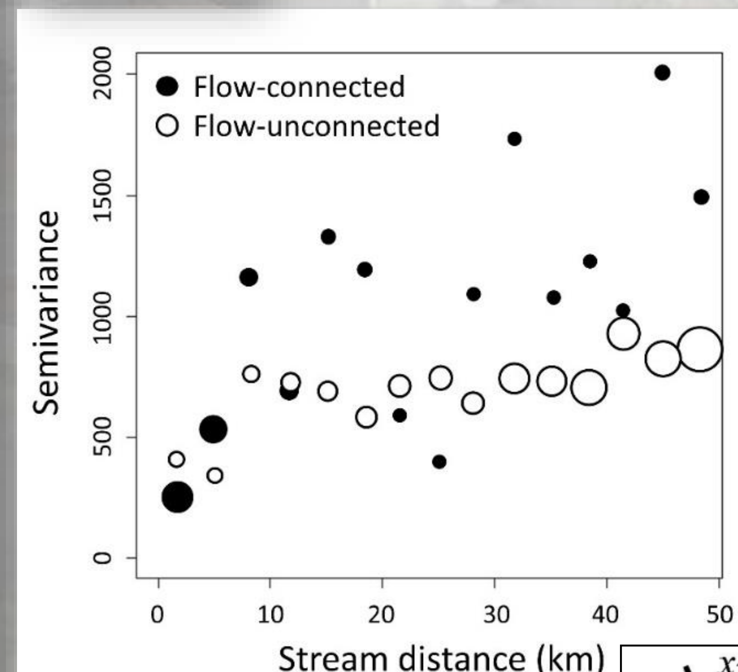
Spatial Correlation in Fish Densities

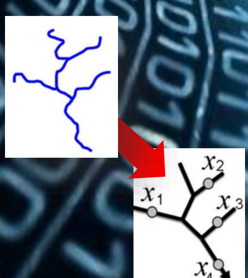


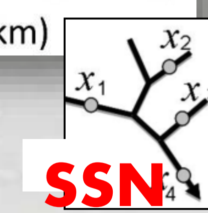
Torgegram (semivariogram for stream networks)



Zimmerman & VerHoef. 2017. The Torgegram for fluvial variography: characterizing spatial dependence on stream networks. *Journal of Computational and Graphical Statistics* DOI: 10.1080/10618600.2016.1247006





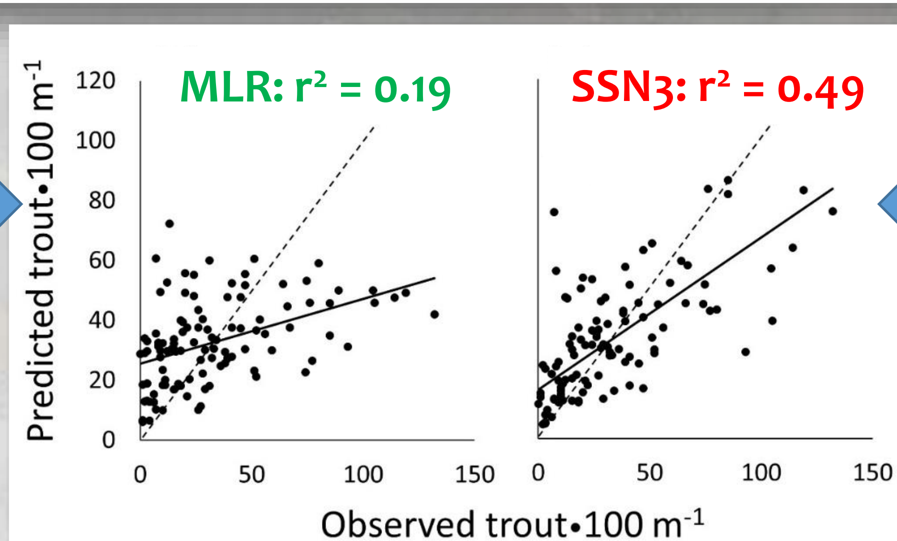


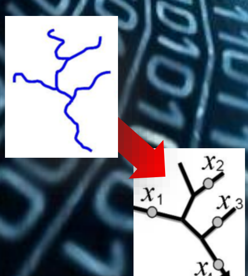
Model Fish Density Dataset w/Covariates

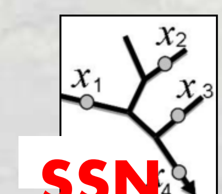
Comparison of SSNs & multiple linear regression (MLR)

Model	Covariate	*b* (SE)	*p* value	Autocovariance*	n_p†	ΔAIC	CV r^2‡	RMSPE§
MLR	Intercept	−55.0 (20.5)	<0.01	—	4	27	0.19	26.3
	Slope	36.7 (126)	0.77					
	Temperature	6.75 (1.43)	<0.01					
	Canopy	0.379 (0.163)	0.02					
SSN1	Intercept	−51.6 (29.1)	0.08	TU, TD	9	1	0.49	21.0
	Slope	103 (103)	0.32					
	Temperature	6.61 (2.22)	<0.01					
	Canopy	0.255 (0.173)	0.14					
SSN2	Intercept	−51.4 (29.7)	0.09	TU, TD, EUC	11	5	0.49	20.9
	Slope	104 (104)	0.32					
	Temperature	6.60 (2.27)	<0.01					
	Canopy	0.249 (0.18)	0.16					
SSN3	Intercept	−18.3 (19.1)	0.34	TU, TD	7	0	0.49	20.8
	Temperature	4.57 (1.67)	<0.01					
SSN4	Intercept	31.9 (5.69)	<0.01	TU, TD	6	5	0.49	20.9
SSN5	Intercept	31.4 (9.00)	<0.01	TU, TD, EUC	8	7	0.50	20.5

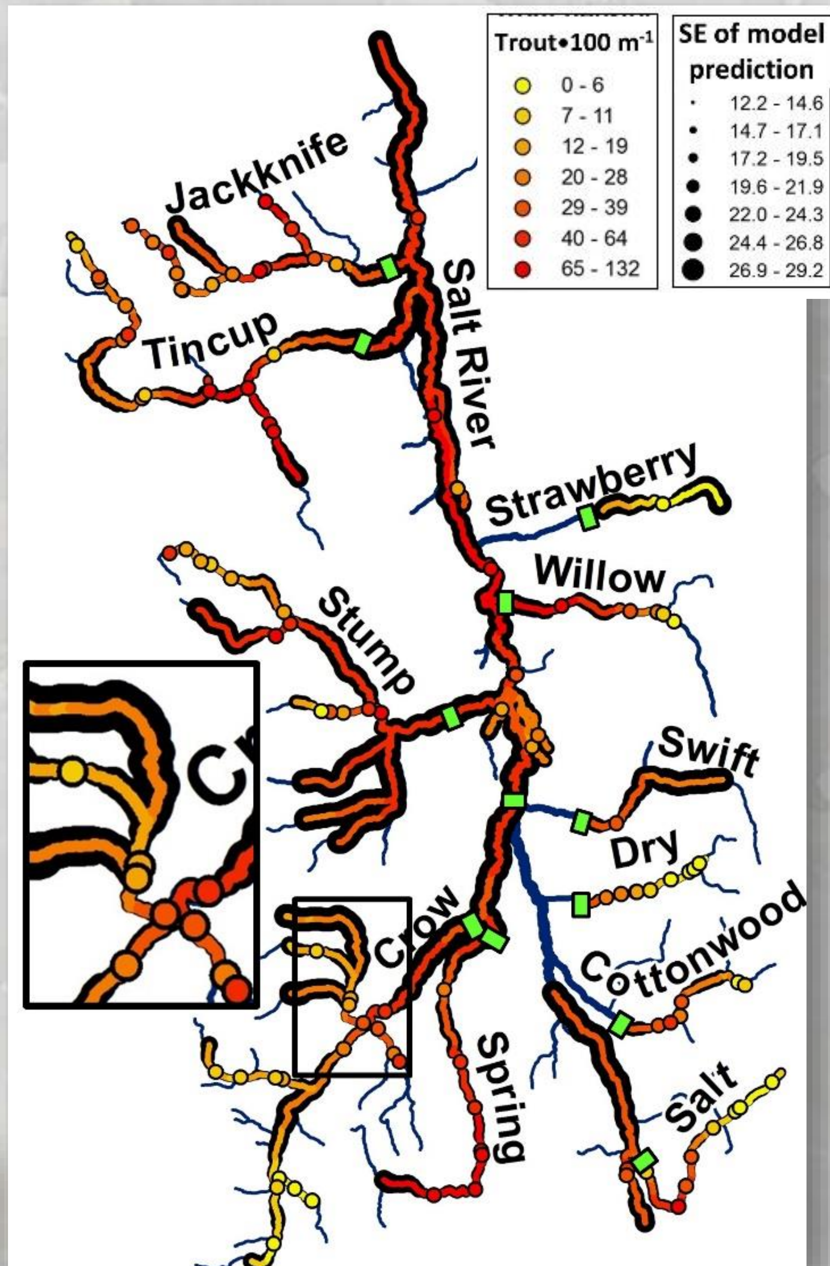
*TU, tail-up; TD, tail-down; EUC, Euclidean.





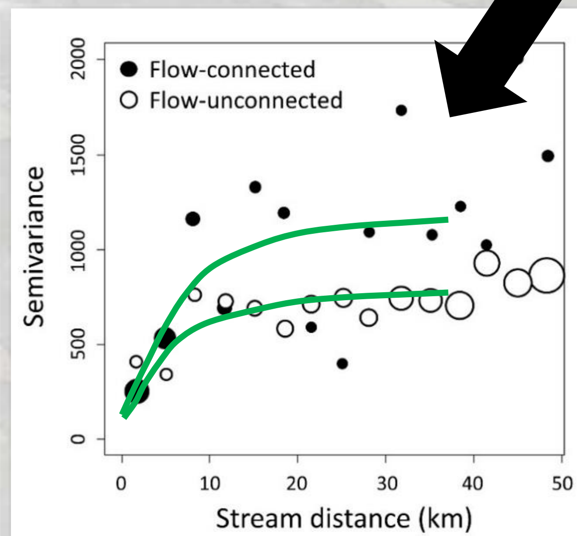


Krige (i.e., predict) Fish Densities & SEs

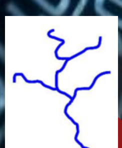


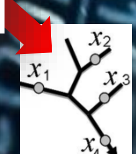
- Kriging routine "honors the data" by matching observed values
- Interpolations based on covariates & autocorrelation function

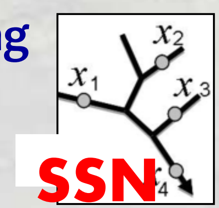
$$Y = b_0 + b_1(x_1) + €$$



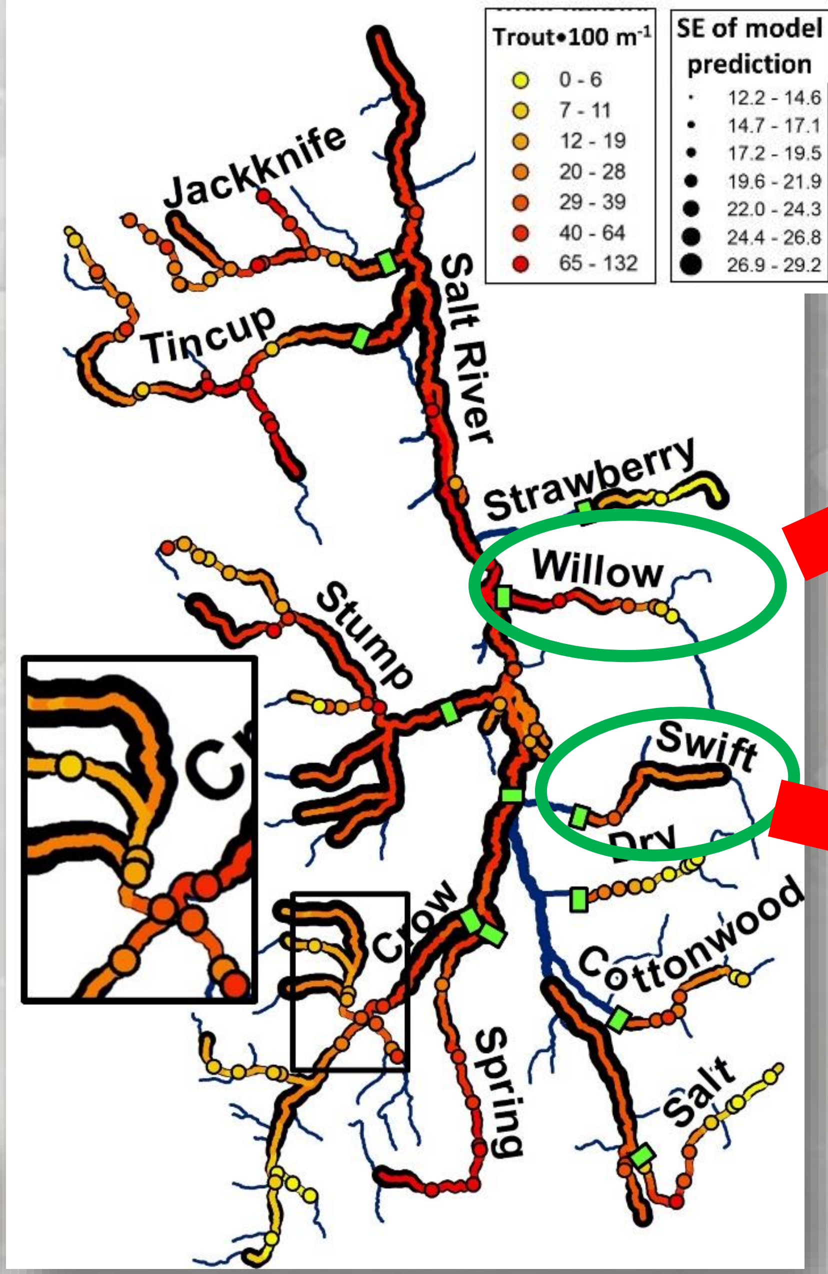
- Prediction precision varies based on local empirical support
- Spatial precision could be used to guide subsequent sampling

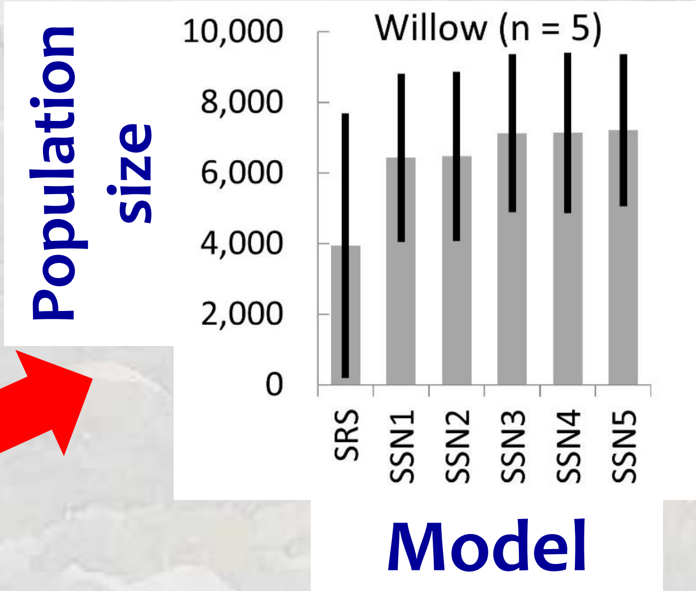


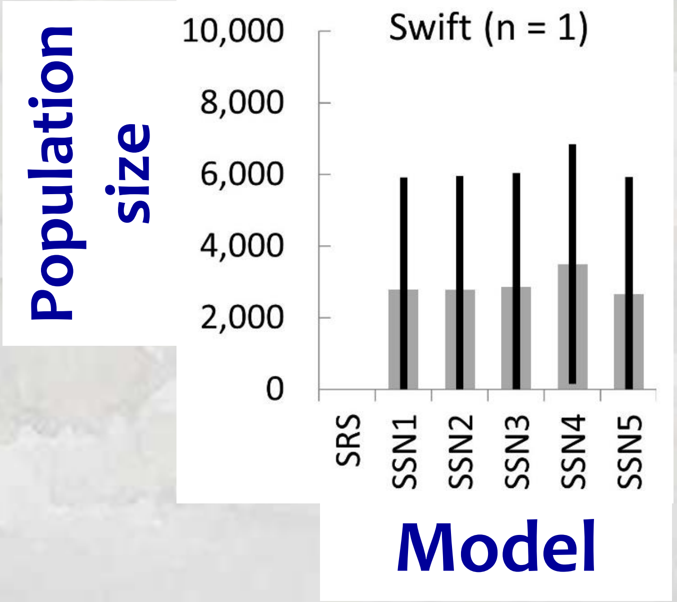


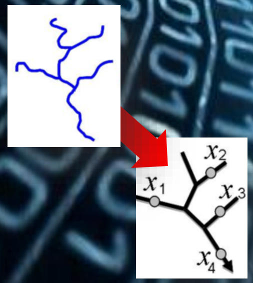


Block-Krige (i.e., summarize) Densities for Population Estimates

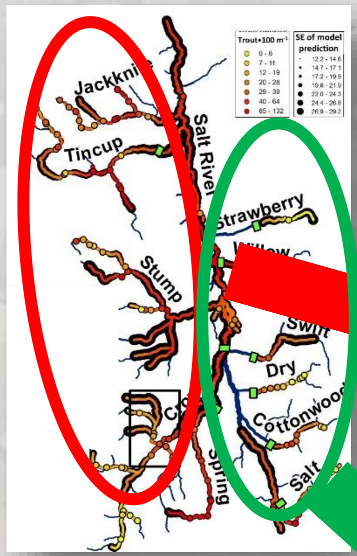


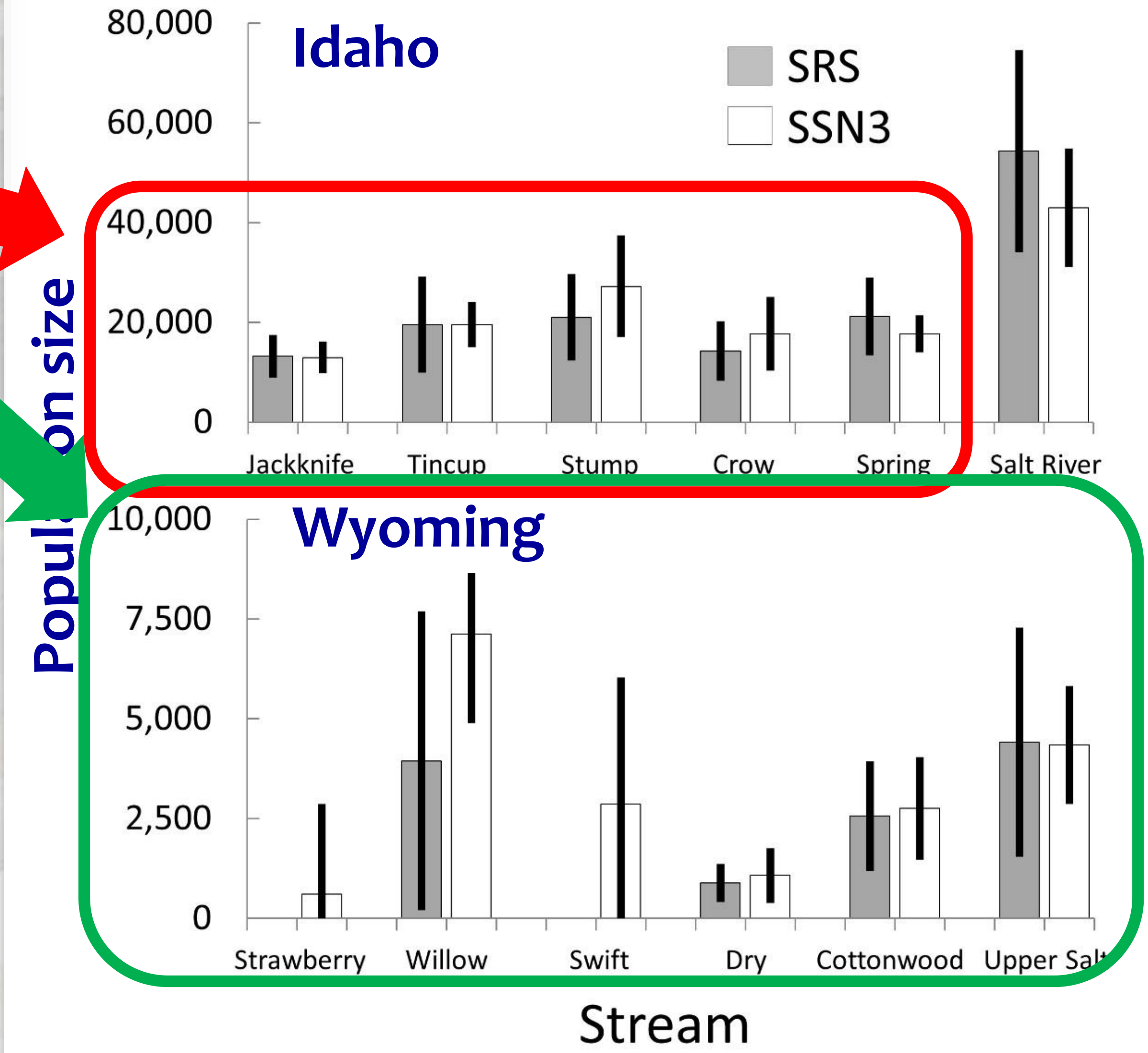


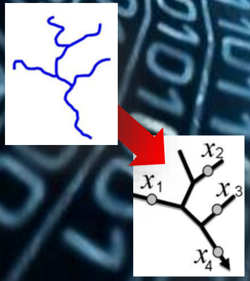




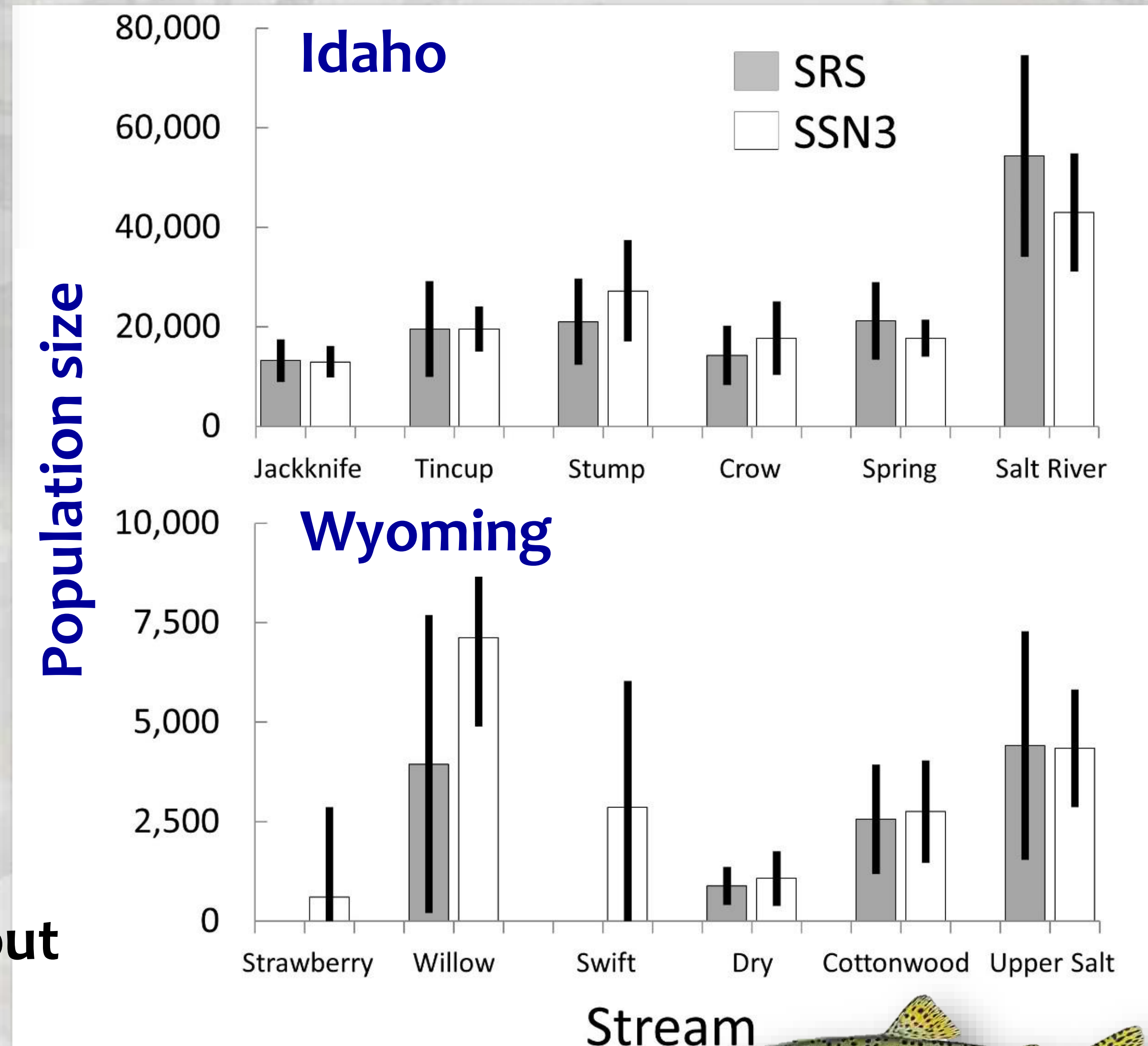
Block-Krige (i.e., summarize) Densities for Population Estimates



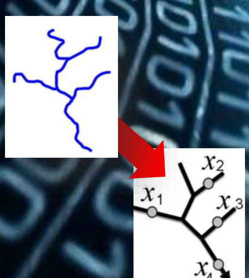




Block-Krige (i.e., summarize) Densities for Population Estimates

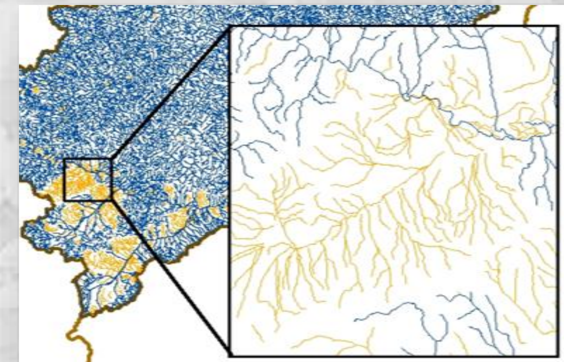


Grand pop. estimate = 184,030 (+/- 27,263) trout



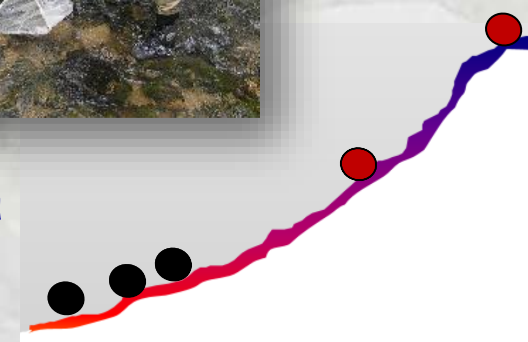
~150,000 age 1+ Yellowstone cutthroat

Caveats:

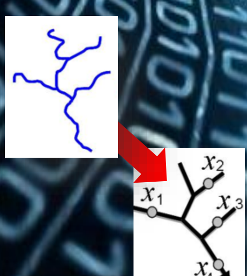


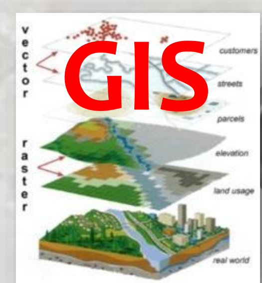
1) Need accurate stream network length – 735 km by reducing NHD 1:100,000-scale bluelines 60% (deleted reaches >10% slope & intermittent (Fcode = 46003))

2) Multipass depletion estimator is biased low (adjust for detection efficiency or use mark-recap?)



3) SSN-BK works with nonrandom data (within reason). Samples should also have geographic breadth





4) GIS & statistical skills needed to run SSN models (2-person teams)

Published & Online; Take it for a Spin

NRC Research Press

RAPID COMMUNICATION

Scalable population estimates using spatial-stream-network (SSN) models, fish density surveys, and national geospatial database frameworks for streams

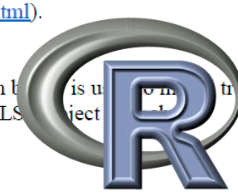
Daniel J. Isaak, Jay M. Ver Hoef, Erin E. Peterson, Dona L. Horan, and David E. Nagel

Can. J. Fish. Aquat. Sci. 00: 1–10 (0000) dx.doi.org/10.1139/cjfas-2016-0247

Supplemental A.
A ZIP file containing the LSN object file "LSN_TroutDensity_BlockKrige.ssn" and ESRI geodatabase "LSN_TroutDensity_BlockKrige.mdb" to replicate the Salt River analysis is downloadable at the SSN/STARS website "Software and Data" subpage (www.fs.fed.us/rm/boise/AWAE/projects/SSN_STARS/software_data.html).

The annotated R script "SaltRiver_TroutDensity_BlockKriging.R" given b[...] is u[...] tr[...]ut densities in the Salt River and derive block-kriging population estimates with the LS[...]ject [...]

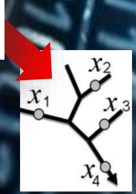
```
#Load SSN package into R
library("SSN")

#Set working directory to location of .ssn directory
setwd("C:\\...")

#import the data from the .ssn directory and create a SpatialStreamNetwork object with basic set of prediction points for all reach midpoints
SaltWQ <- importSSN("lsndata/LSN_TroutDensity_BlockKrige.ssn", predpts = "preds")
```



Script

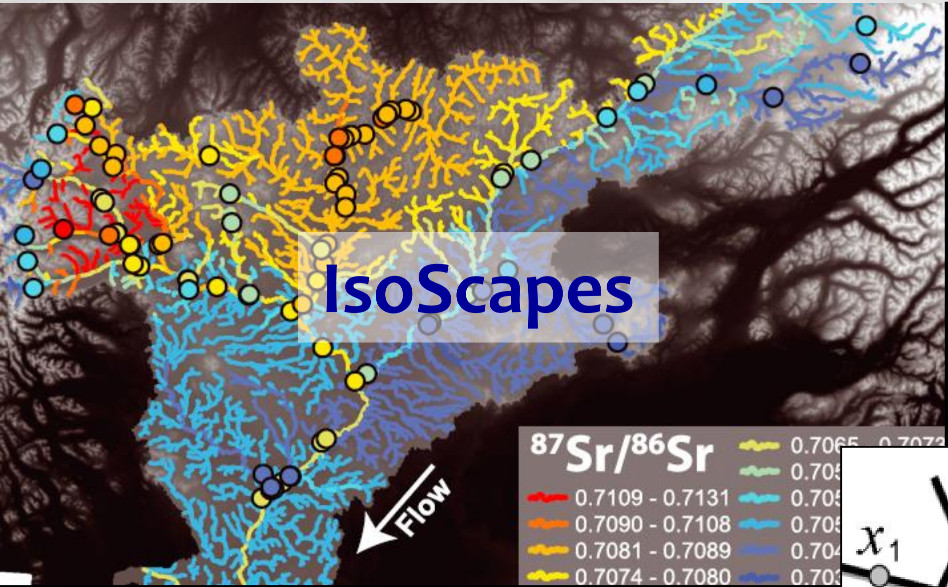
	A	B	C
1			
2	Stream:	Elk Creek	
3	Georeference:	610234 E, 4402546 W	
4			
5	Date	Time	Temp (°C)
6	[illegible]	[illegible]	15.59
7	[illegible]	[illegible]	15.11
8	7/15/2005	22:23	14.64
9	7/15/2005	22:53	14.32
10	7/15/2005	23:23	13.86
11	7/15/2005	23:53	13.55
12	7/16/2005	0:23	13.24

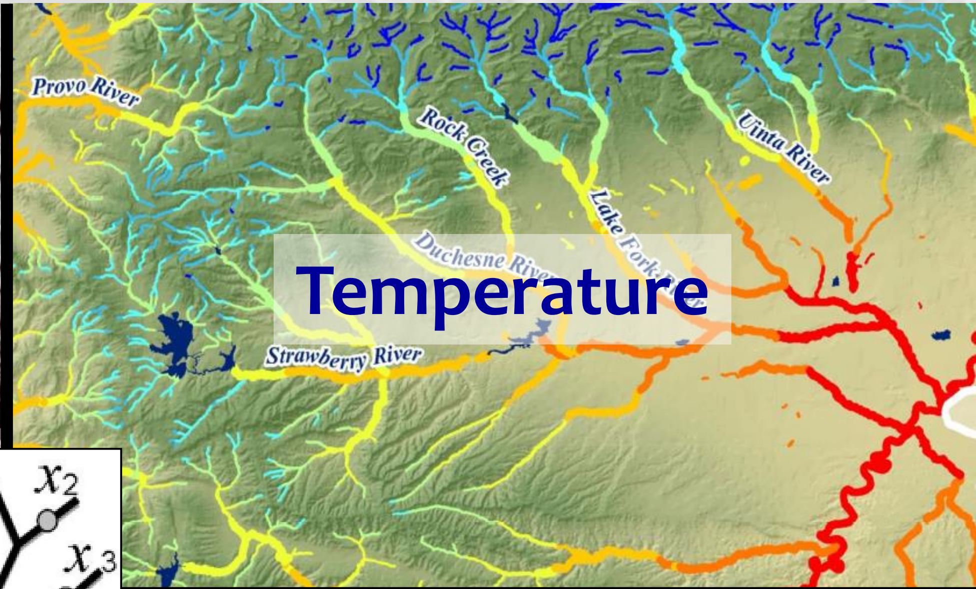
Dataset

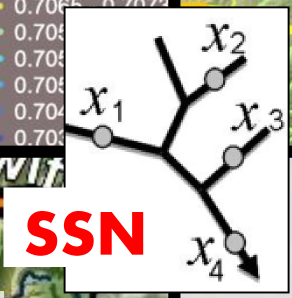


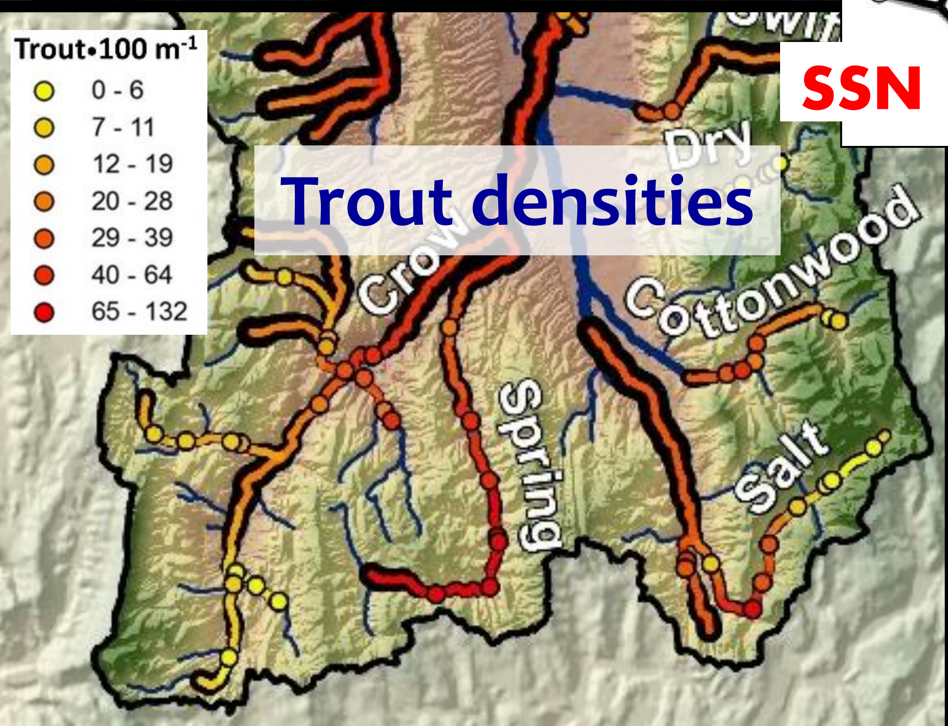
SSN & STARS Website – Tools for Spatial Modeling on Stream Networks:
https://www.fs.fed.us/rm/boise/AWAE/projects/SpatialStreamNetworks.shtml

Stream Networks & Statistics are Cool









Your Data Here!

5th annual SSN training workshop
March 29-31/April 3-5 (full already)