Northwest **Power** and **Conservation** Council



December 5, 2023

**MEMORANDUM**

**TO:** **Council Members**

**FROM:** **Mark Fritsch**

**SUBJECT:** **Update on technical service contract Project #2017-002-00, *Analysis of Spatial Stream Networks for Salmonids***

## BACKGROUND:

Presenter: Jody Lando - *Research, Monitoring and Evaluation Lead for Bonneville Power Administration*; and
Dan Isaak, *Research Fish Biologist for Rocky Mountain Research Station, U.S. Forest Service*

Summary: Dan will provide a summary of work completed under contract with Bonneville, associated with Project #2017-002-00, *Analysis of Spatial Stream Networks (SSN) for Salmonids ("FDAT")* a technical services contract[1] to develop linear networks for salmon densities using spatial statistics and GIS stream networks. This work was conducted by the US Forest Service Rocky Mountain Research division(s) NorthWest Stream Temperature (NorWeST) team with NOAA and Queensland University. The products from this exploratory effort intended to support tributary habitat restoration planning and support a proposed action commitment to monitoring temperature.

[1] Technical service contracts (TSC) are categorized as Bonneville Program Support (i.e., provide expertise and/or capacity to Bonneville staff) – *A project that supports the (direct) Program but is not included in a Council recommendation or ISRP review*.

Relevance: This work was designed to test novel methods of incorporating fish distribution monitoring data into updated fish distribution maps.

Workplan: 2023 Fish and Wildlife Division Work Plan; Program Planning and Coordination.

Background: This effort was developed in three phases.

- **Phase 1, 2018:** Develop linear networks and related web-tools for modeling salmonid density (carrying capacity) and habitat relationships relative to temperature, flow, and other covariates using Spatial Stream Networks (SSN) models and the National Hydrography Dataset Network. Working with United States Forest Services Rocky Mountain Research Center in partnership with Queensland University of Technology and the NOAA-NMFS Alaska Fisheries Science Center, Bonneville explored opportunities to aggregate and format fish monitoring data in an efficient interface, with tools to inform tributary habitat prioritization efforts, life cycle models, and fish trends information limited to the Grande Ronde River.

- **Phase 2, 2019:** Support Phase 2 development of the Fish Data Analysis Tools (FDAT) linear networks for salmon and steelhead. This phase included an expanded geographic scope (John Day, Salmon and Clearwater basins) and ODFW and IDFG sources of data with the goal of improving estimate precision.

    - **NorWeST Phase 2: FY 2021-22:** BPA funded a NorWeST temperature dataset update along with USFWS cost share to ensure Bonneville funded M&E was added to a stream temperature network update. The work provided estimates of winter lows and updated the existing data set from 2013 to include more recent data.

- **Phase 3, 2022-23:** additional FDAT development for salmon and steelhead, using a proposed exchange standard to support NOAA's 2020 Biological Opinion terms and conditions to provide carrying capacity products to the Tributary Habitat Steering Committee to inform restoration planning and prioritization for Chinook salmon.

The result of this exploratory effort appears to be reliable and as such, could provide valuable data input to support tributary habitat restoration planning as well as a proposed action commitment to monitor stream temperature. For the future there may be opportunities to explore development of exchange processes to automate update of the FDAT and potentially coordinated with StreamNet. If this initiative is to be supported

through the direct fish and wildlife program, staff recommends prioritization, and a project review and recommendation, as typical for a project like this.

More Info:

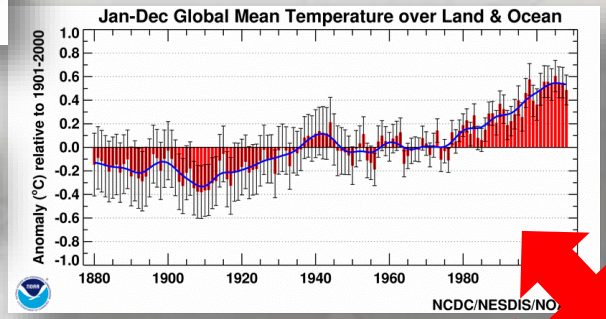
- NorWest Stream Temperature- Regional Database and Model: This website hosts a comprehensive interagency stream temperature database and high resolution climate scenarios for the Northwest U.S.

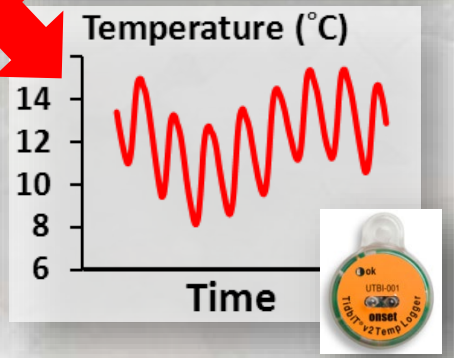
# NorWeST Stream Temperature Project Updates & Applications With the Fish Density Analysis Tool (FDAT)

Dan Isaak, Erin Peterson, Jay VerHoef, Dave Nagel, Gwynne Chandler, Sharon Parkes, Sherry Wollrab, Dona Horan, and Will Dubois

Northwest Power and Conservation Council

December 13, 2023




## Recent Funding:

Bonneville Power Administration

Forest Service, U.S. Department of Agriculture

## Original Funding:

North Pacific Landscape Conservation Cooperative

Great Northern Landscape Conservation Cooperative

U.S. Fish & Wildlife Service

California Fish Passage Forum

NASA

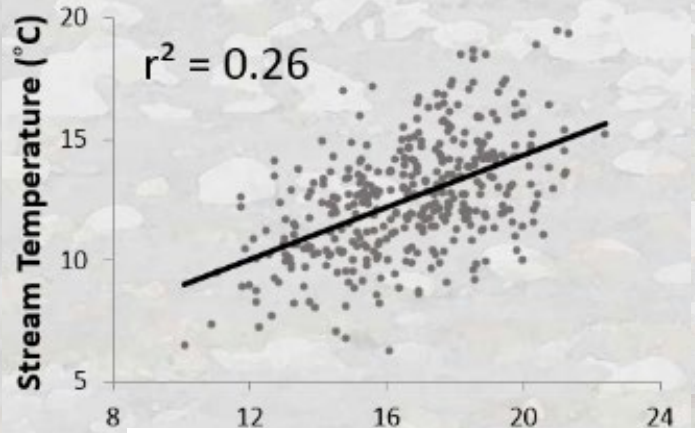
U.S. Department of the Interior, Bureau of Land Management

# NorWeST's Motivation: Temperature is Destiny for Cold-Water Fish Species

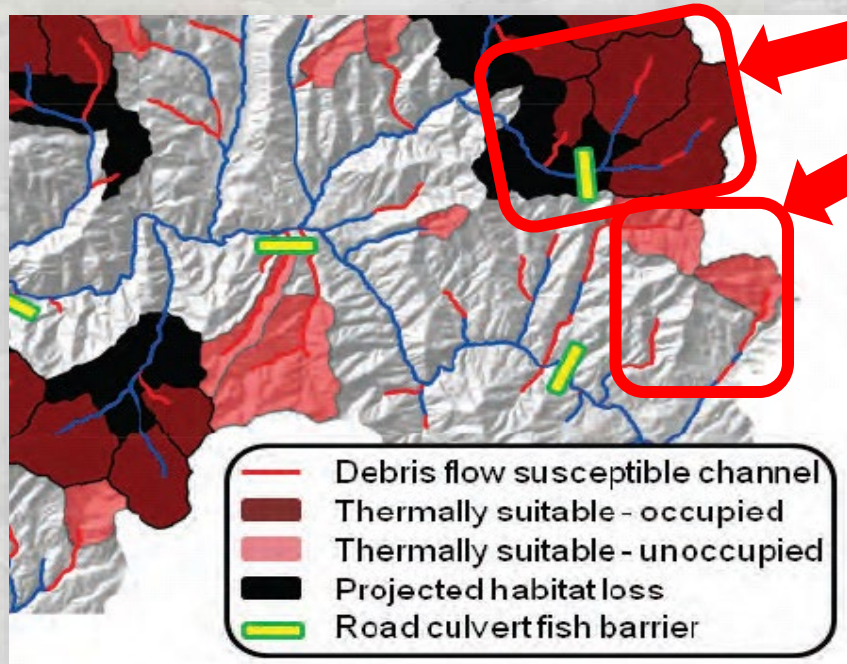
**Thermal controls on:**

- Metabolic rates & stress responses
- Foraging & migratory behaviors
- Distributions & abundance
- Phenology
- Life history expression
- Evolutionary trajectories

**Commonly used stream temp surrogates were imprecise**

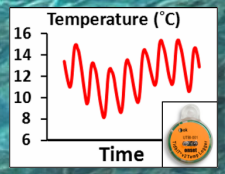



**Accurate, high-resolution information needed for project-level planning**

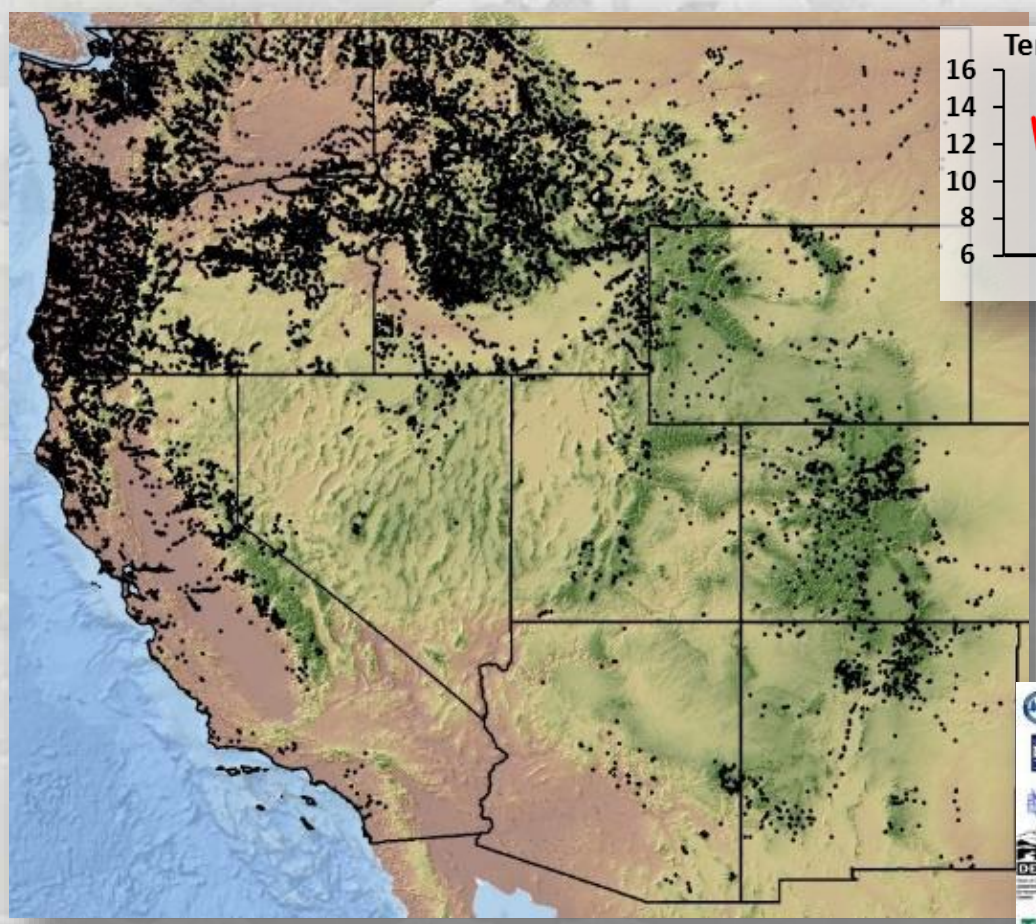


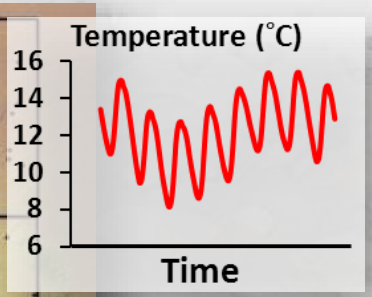

**I'm going to invest here…**

**… instead of here**



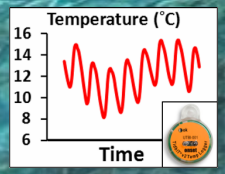
# Miniature Sensors Made Stream Temperature Data Collection Easy 30 Years ago…








- >23,000 unique monitoring sites
- Dozens of agencies monitor stream temperatures in the West



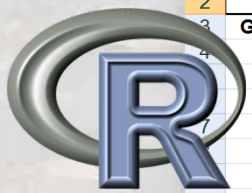
# Data ≠ Database, hence…

NorWeST Stream Temp

## Data Aggregation




## QA/QC Data Cleaning



| | A | B | C |
|---|---|---|---|
| 1 | | | |
| 2 | **Stream:** | Elk Creek | |
| 3 | **Georeference:** | 610234 E, 4402546 W | |
| 4 | | | |
| 5 | **Date** | **Time** | **Temp (*C)** |
| 6 | 7/15/2005 | 21:23 | 15.59 |
| 7 | 7/15/2005 | 21:53 | 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 |

## Data Summaries & Georeferencing

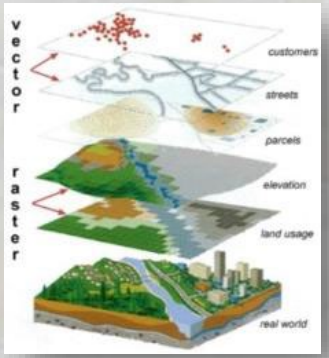
Mean

Minimum

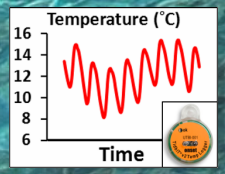
Maximum

ArcGIS ESRI

## Metadata & Digitally Archiving

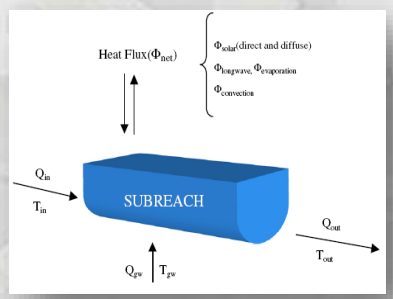




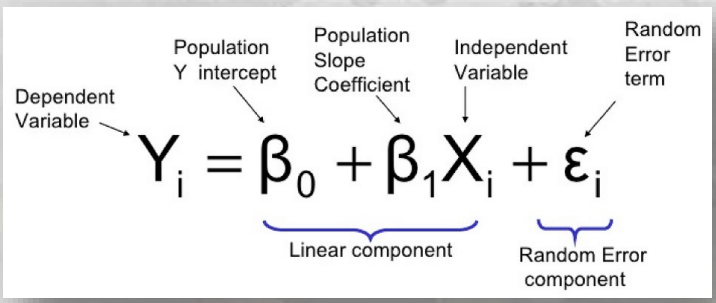


# NorWeST Database Enables Many Types of Stream Temperature Models for Multiple Purposes

## Mechanistic models




## Statistical models




## Spatial-Statistical Network (SSN) Models: Ideal for large, spatially clustered datasets on stream networks

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

ORIGINAL ARTICLE

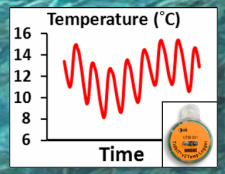
**Spatial statistical models that use flow and stream distance**

Jay M. Ver Hoef · Erin Peterson · David Theobald

**2006**

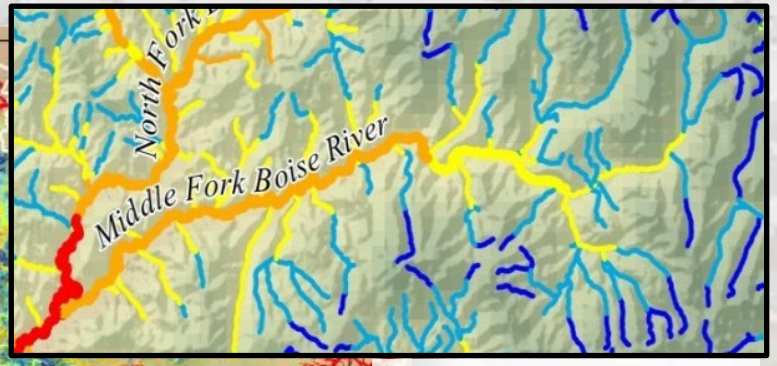
*Journal of Statistical Software*

*January 2014, Volume 56, Issue 3.* *http://www.jstatsoft.org/*



# High-Resolution Stream Temperature Scenarios

## 44 Historical & Future Scenarios



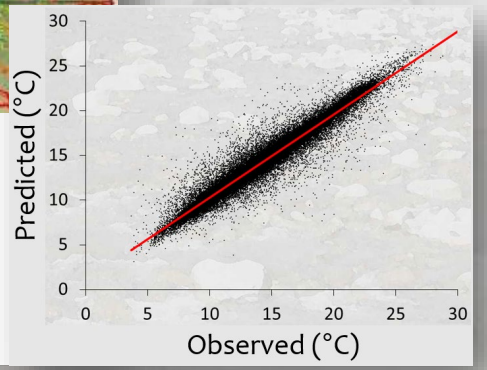

**1-km resolution**
**1,600,000 km of rivers & streams**

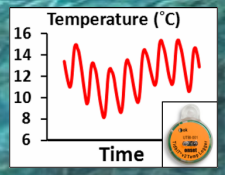



$r^2 = 0.91$

**RMSPE = 1.10°C**

**MAPE = 0.72°C**

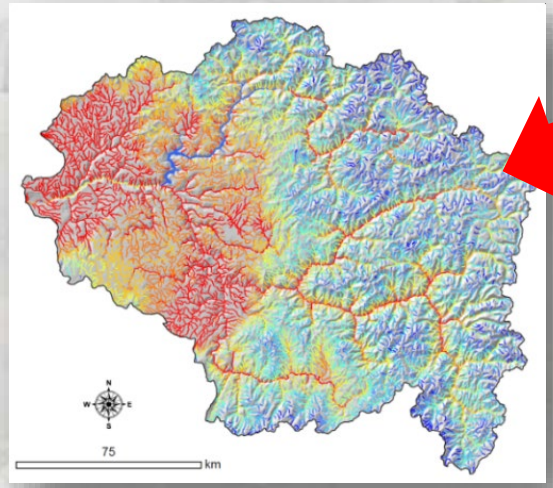



Isaak et al. 2017. The NorWeST summer stream temperature model & scenarios for the western U.S. Water Resources Research 53: 9182-9205.

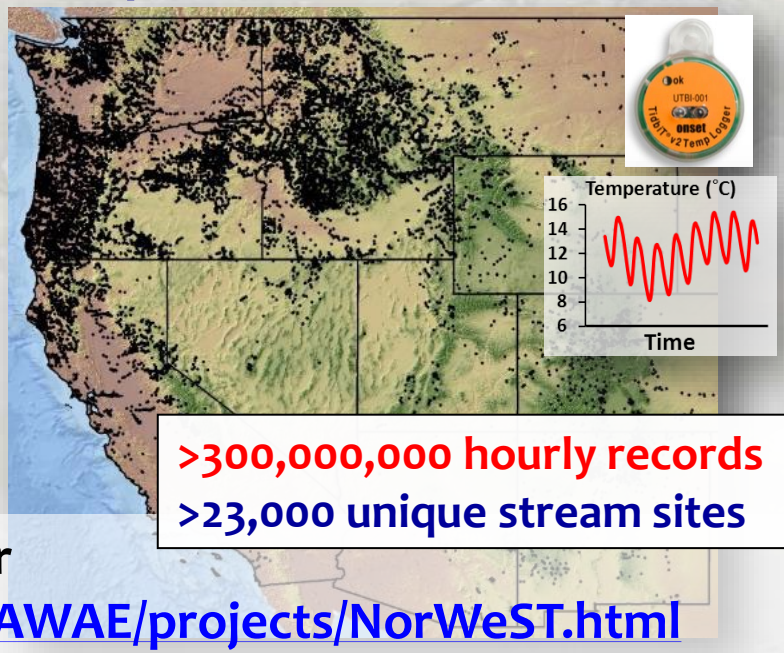
# NorWeST Website Distributes Temperature Datasets & Model Prediction Scenarios

## Prediction scenario maps for NHD streamlines



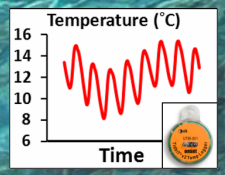


## Temperature data summaries



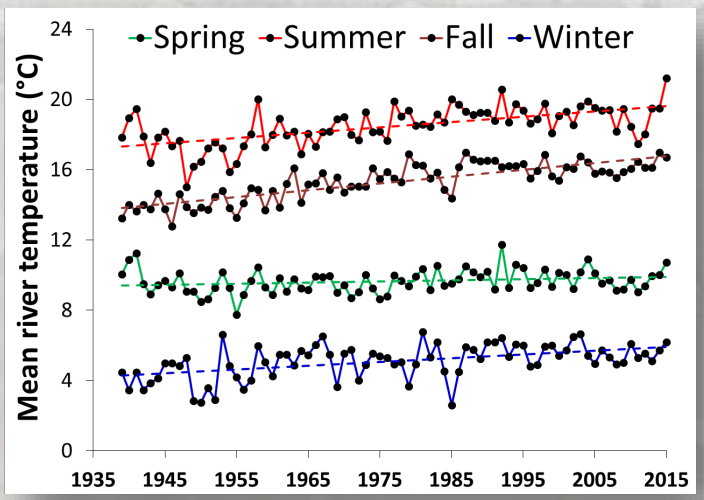

- ArcGIS shapefiles
- .pdf maps
- Excel file spreadsheets
- Dynamic mapping tools

**>300,000,000 hourly records**
**>23,000 unique stream sites**

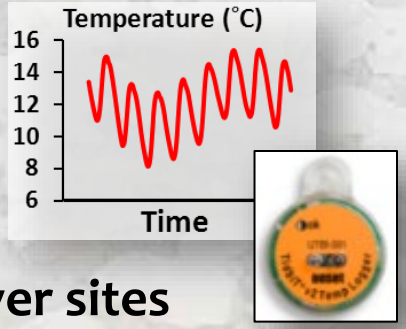



Google "NorWeST stream temp" or
https://www.fs.usda.gov/rm/boise/AWAE/projects/NorWeST.html

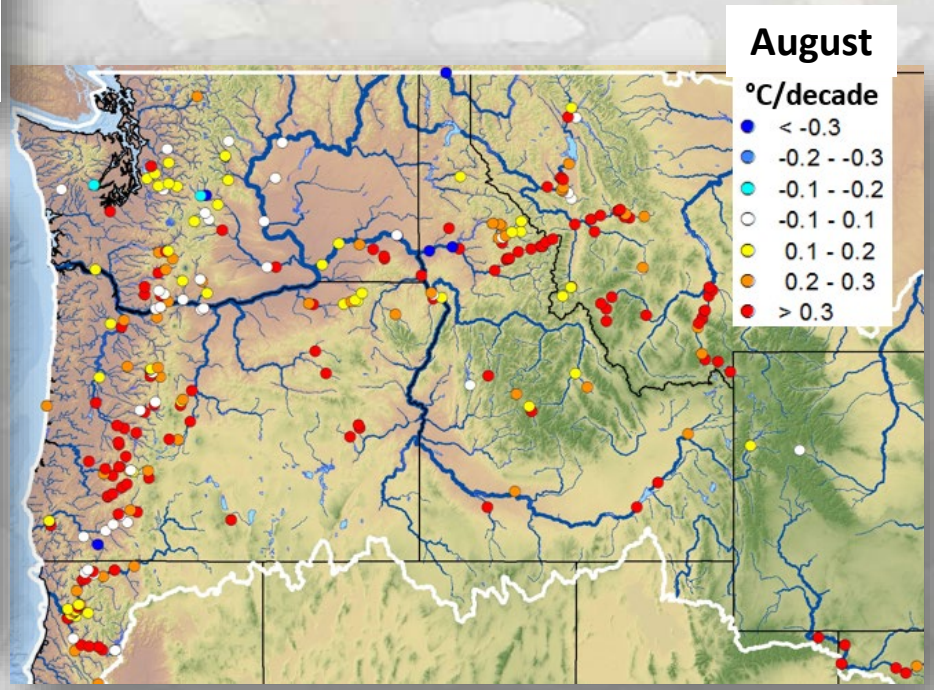
# NorWeST Application: Determining Rates at Which PNW Rivers are Warming

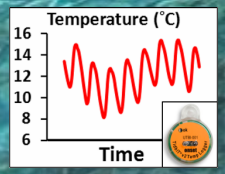



## Bonneville Dam Temperature Record




- n = 345 long-term river sites
- 1976–2015 trend: ~0.15–0.3 °C/decade
- Most warming: summer & fall

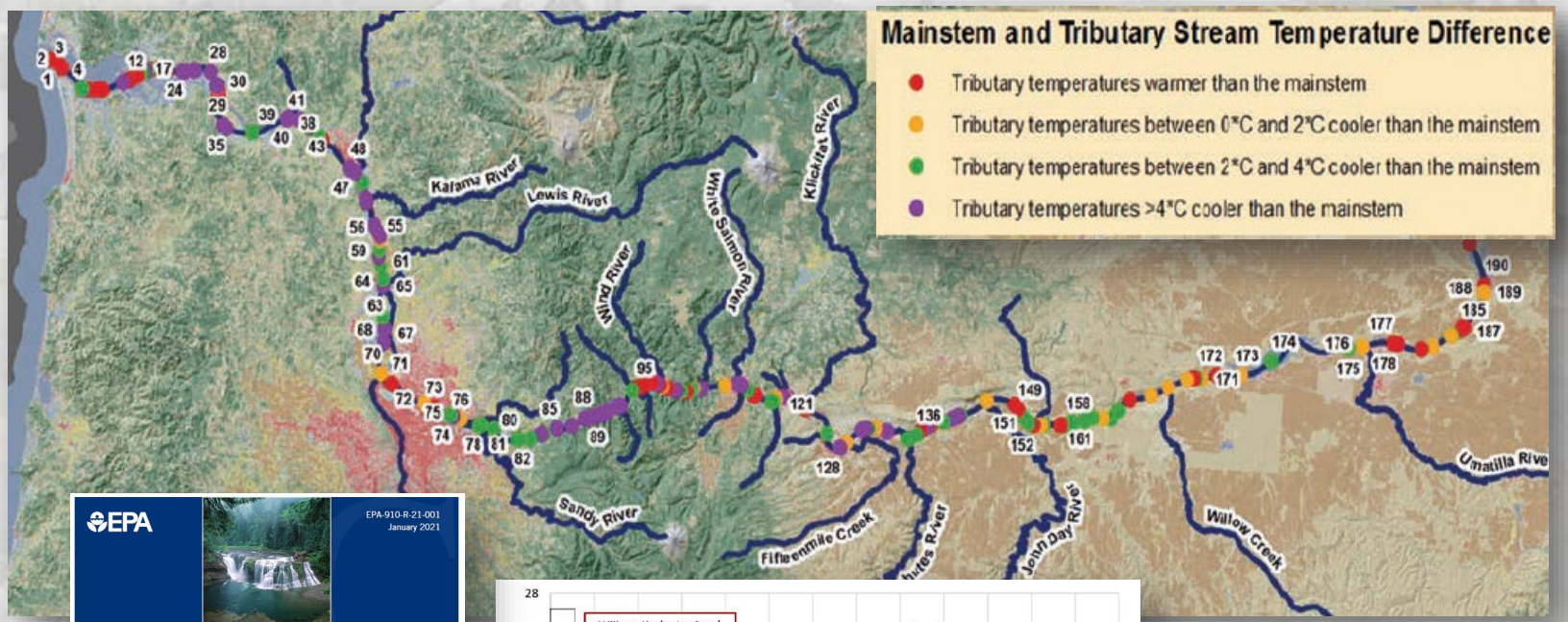


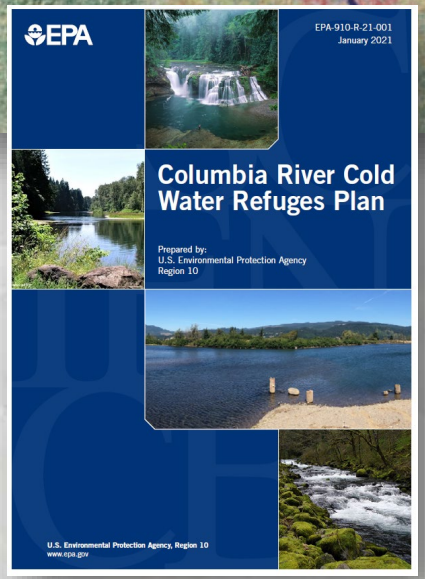



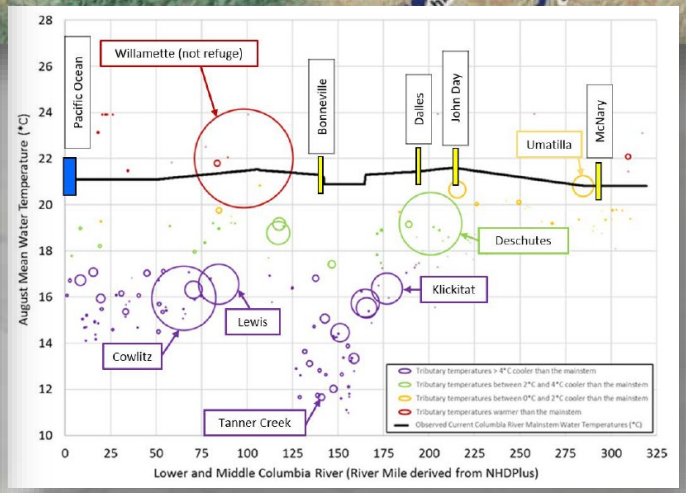

Isaak et al. 2018. Global warming of salmon and trout rivers in the Northwestern U.S. Road to ruin or path through purgatory? *Transactions of the American Fisheries Society* 147:566.

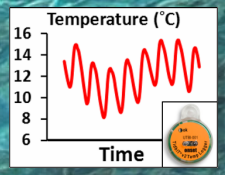
# NorWeST Application:

## Columbia River Coldwater Refuges Plan



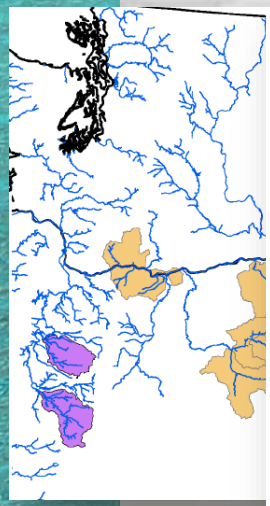



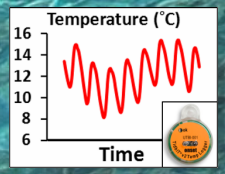



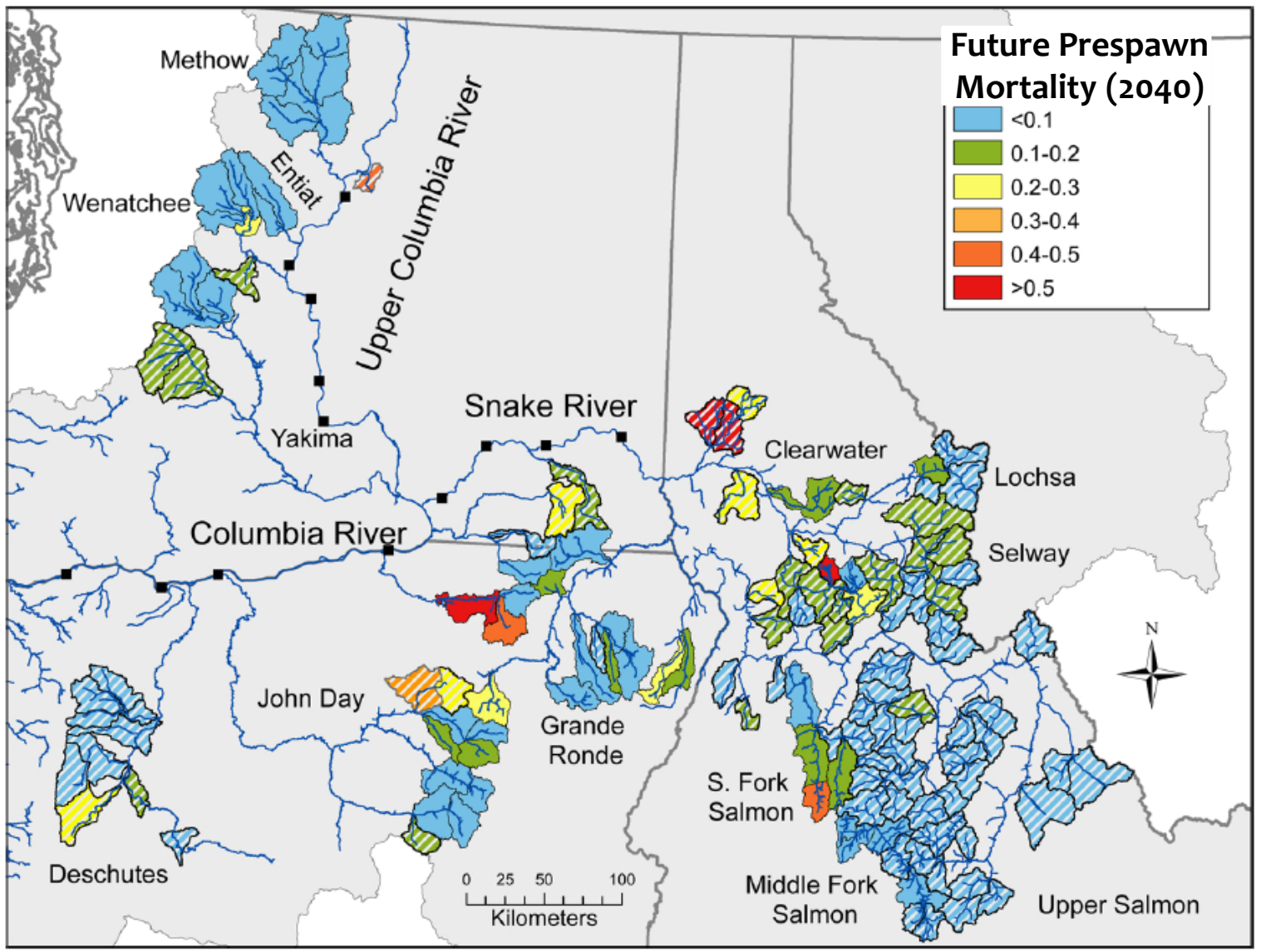

Palmer et al. 2021. Columbia River Cold Water Refuges Plan. U.S. Environmental Protection Agency Region 10 report EPA-910-R-21-001. Portland, OR.

# NorWeST Application: Modeling Prespawn Mortality Rates in Chinook



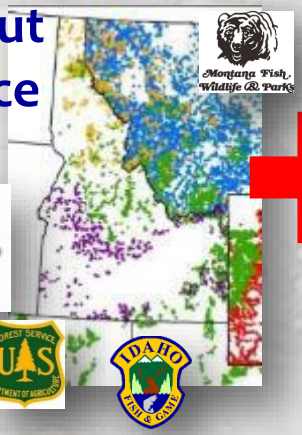


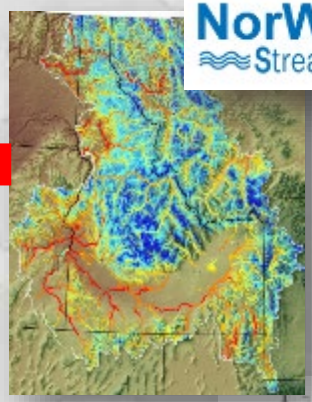

Bower
tempe



# NorWeST Application: Delineating Long-Term Climate Refugia for Native Trout Populations

**Large trout occurrence datasets**

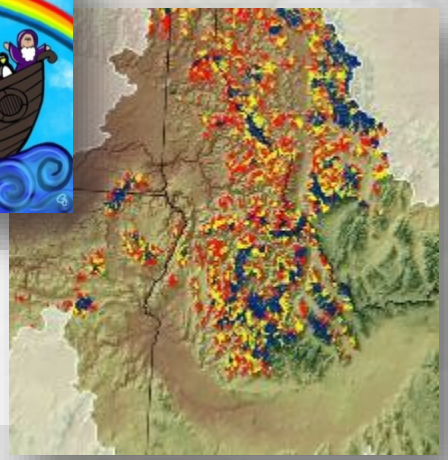


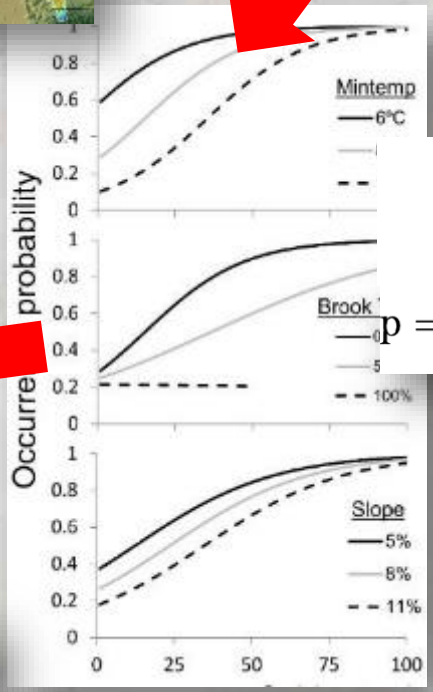



NorWeST Stream Temp

**Additional Covariates**

1. Temperature (°C)
2. Patch slope (%)
3. Patch size (km)
4. Brook trout prevalence

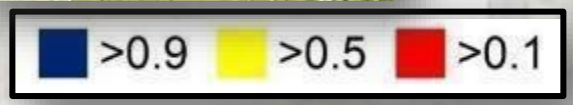


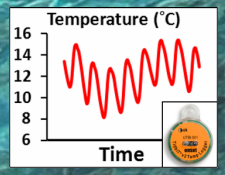



**Predictive Model Response Curves**

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

**Streams with highest potential for population persistence**

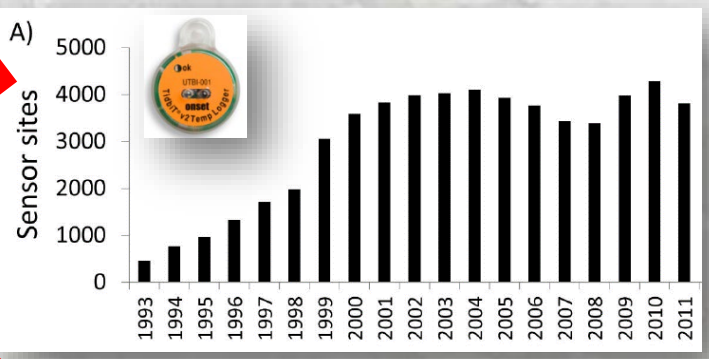


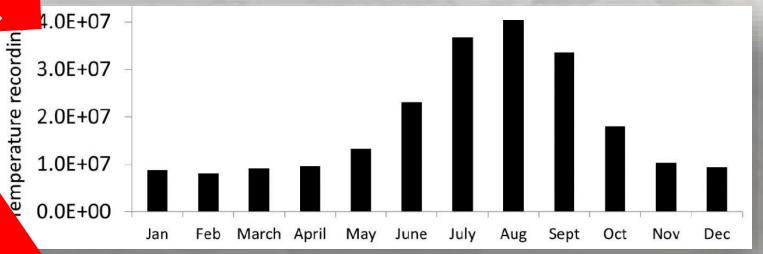



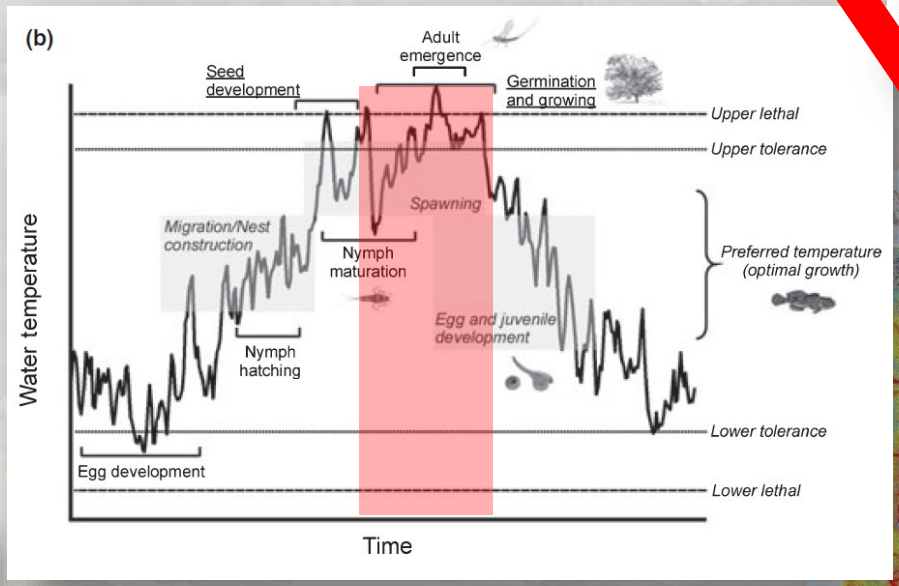

Isaak et al. 2015. The cold-water climate shield: Delineating refugia for preserving native trout through the 21st Century. Global Change Biology 21: 2540-2553

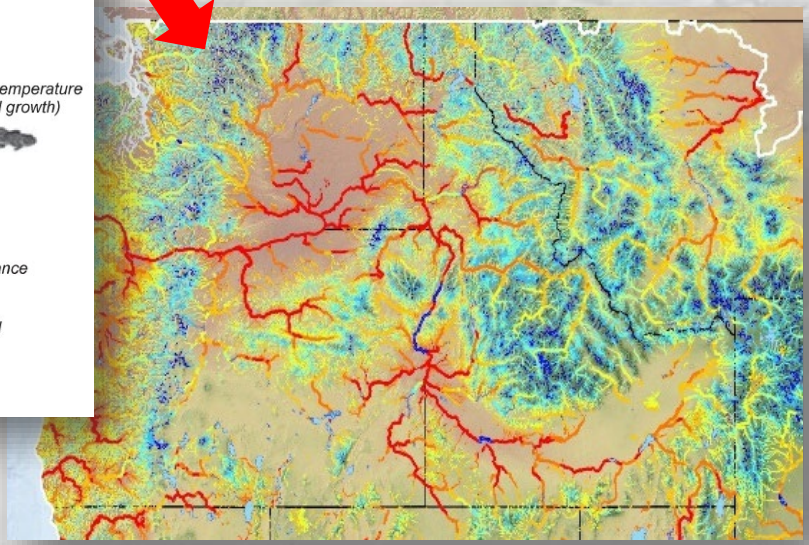
# NorWeST 1.0 Had Some Limitations

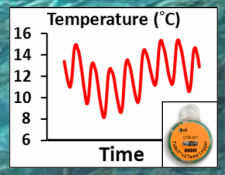
- Database included temperature records only through 2011/2013 for PNW streams
- Most data were from summer rather than annual monitoring
- Modeled scenarios predicted only summer temperature metrics





# NorWeST 2.0 Funded by BPA & USFS

## Focus: Interior Columbia Basin areas accessible to anadromous fish

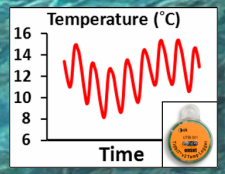

**Objectives:**

1) Aggregate, organize, & integrate new data into NorWeST database & post to website for public access

**~75% of cost share**

2) Analysis to create annual monthly scenarios for past & future climate conditions

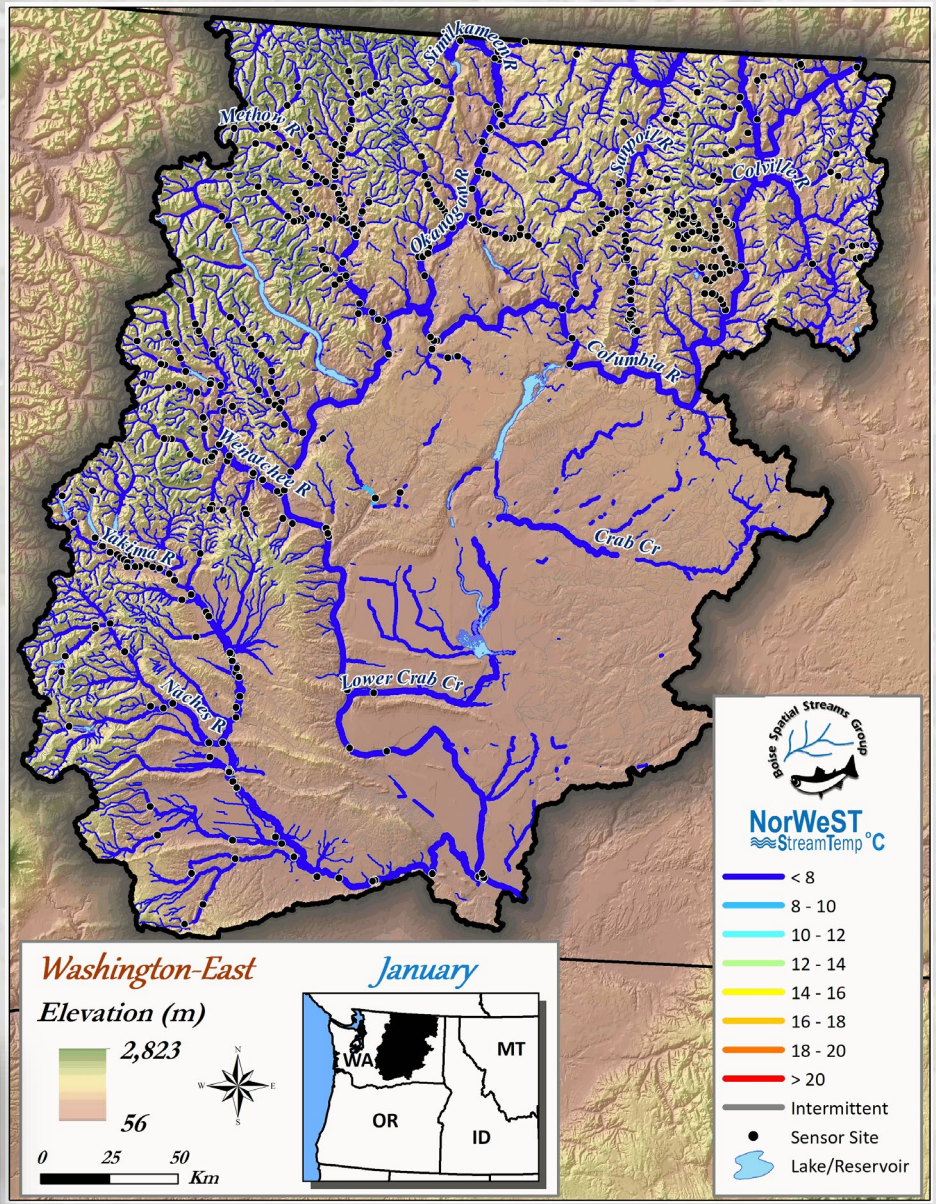
**~25% of cost share**

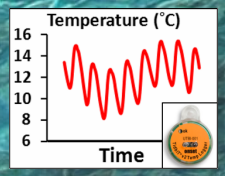



Isaak et al. 2022. Stream temperature monitoring and modeling in the upper Columbia River, Phase 3 report: Spatial stream network (SSN) analysis for salmonids. Bonneville Power Administration Project 2017-002-00 Experimental Stream Network Analysis report. Portland, OR.

# Upper Columbia River Unit:

## Annual Thermal Cycle

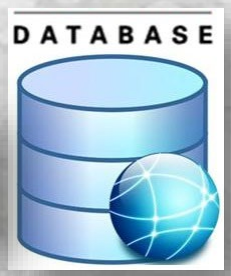



## New Scenarios Consist of:

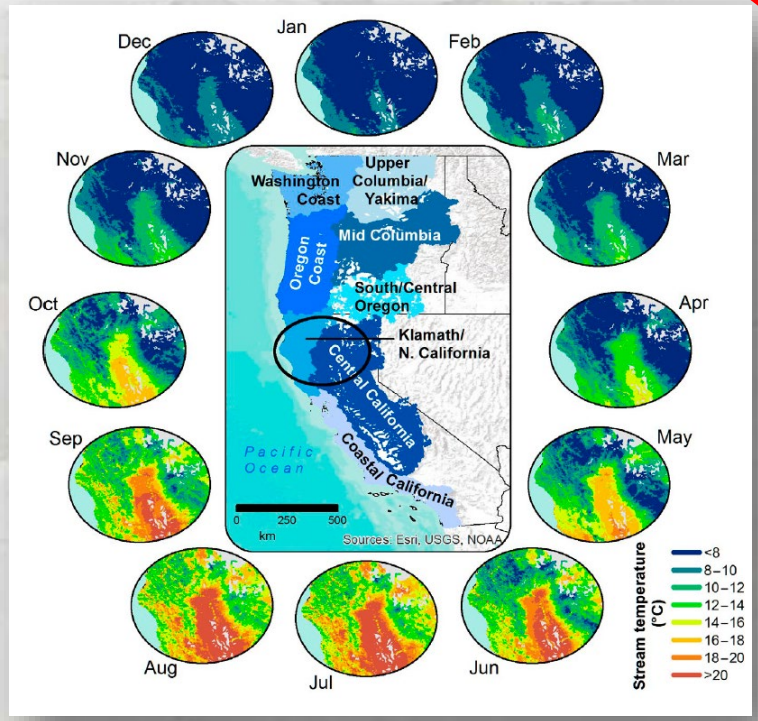
- Predictions maps for 14 thermal metrics (12 months plus annual maximum & minimum)
- 44 different historical & future scenarios for each metric
- 1-km spatial resolution
- Available as ArcGIS shapefiles from website

# NorWeST Datasets Have Facilitated Additional Modeling & Scenario Development Efforts



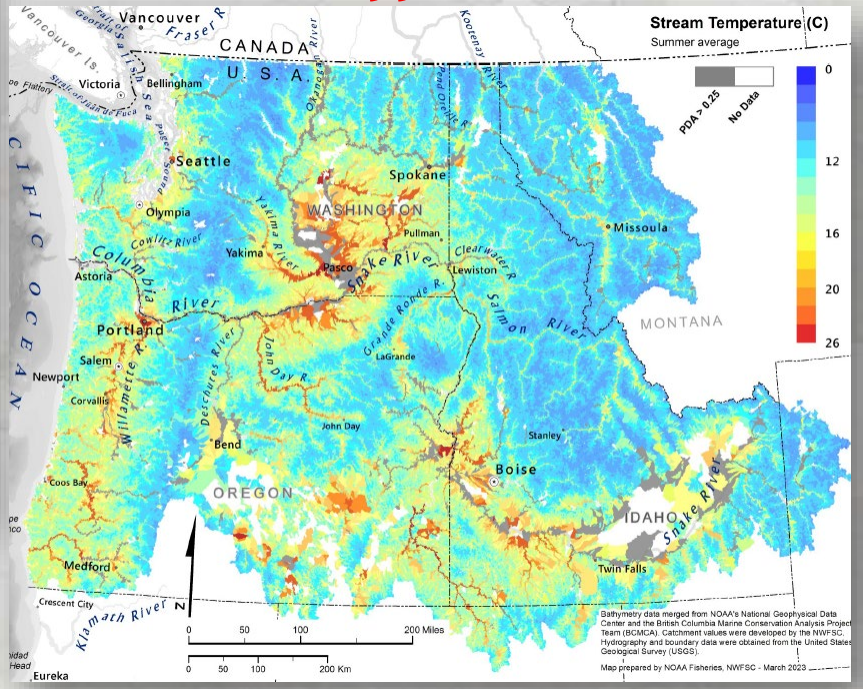

NorWeST Stream Temp

## 1) Annual monthly temperature scenarios for Pacific coast

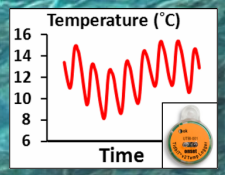



FitzGerald et al. 2021. Quantifying thermal exposure for migratory riverine species: Phenology of Chinook salmon populations predicts thermal stress. Global Change Biology 27:536-549.

## 2) Daily PNW stream temperature scenarios for 1990 2020



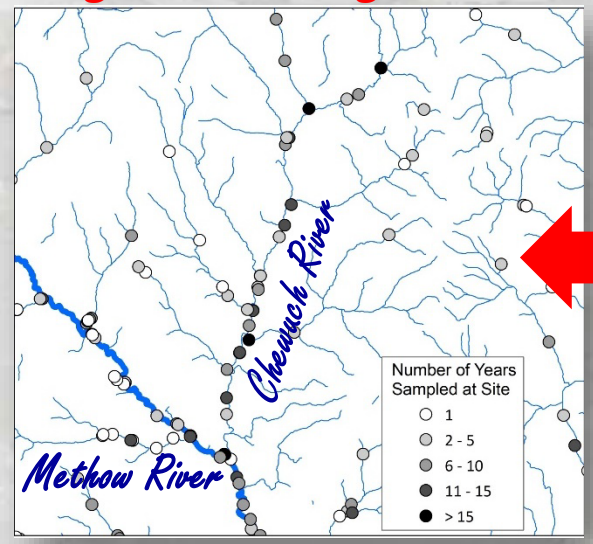

Siegel et al. 2023. Daily stream temperature predictions for free-flowing streams in the Pacific Northwest, USA. PLOS Water 2(8): e0000119



# NorWeST Datasets Could Help Inform More Efficient Sampling Strategies

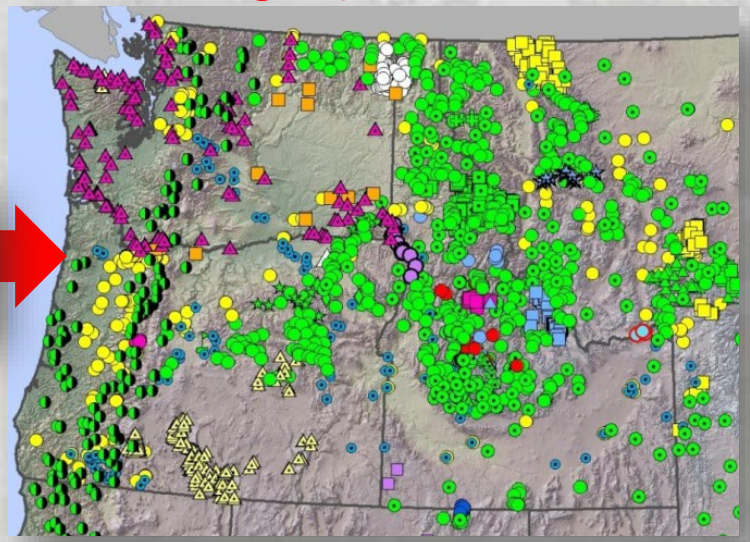
## Simple awareness of when & where data exist

August monitoring sites





Interagency coordination



## Formal sampling design strategies

PLOS ONE

RESEARCH ARTICLE

SSNdesign—An R package for pseudo-Bayesian optimal and adaptive sampling designs on stream networks

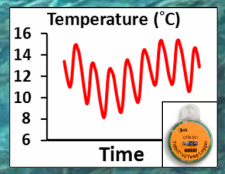
Alan R. Pearse[1,2]*, James M. McGree[2,3], Nicholas A. Som[4,5], Catherine Leigh[1,2], Paul Maxwell[6], Jay M. Ver Hoef[7], Erin E. Peterson[1,2,3]

Research Article | Environmetrics

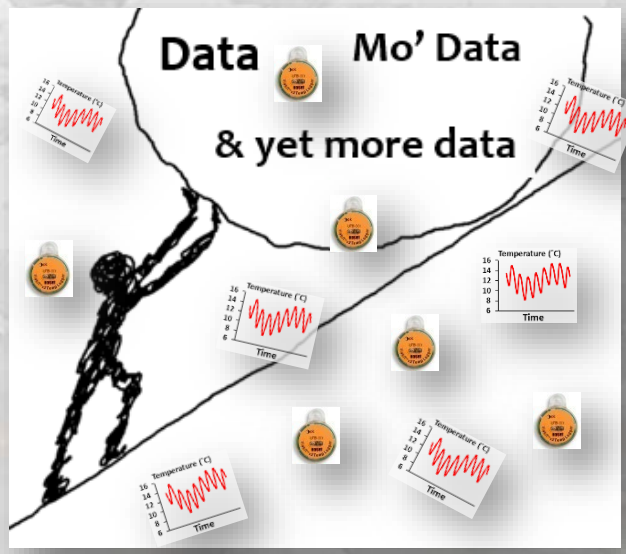
Received: 27 September 2013, Revised: 29 March 2014, Accepted: 21 April 2014, Published online in Wiley Online Library (wileyonlinelibrary.com) DOI: 10.1002/env.2284

**Spatial sampling on streams: principles for inference on aquatic networks**

Nicholas A. Som[a*], Pascal Monestiez[b], Jay M. Ver Hoef[c], Dale L. Zimmerman[d] and Erin E. Peterson[e]



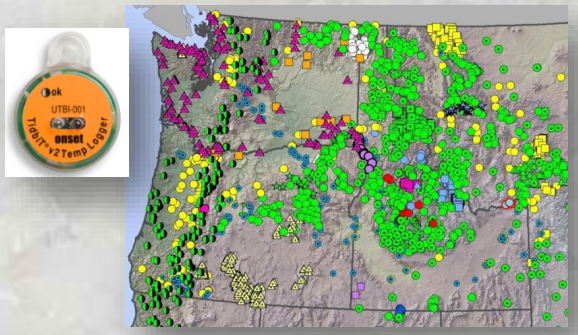
# The Future of PNW Stream Temperature Monitoring



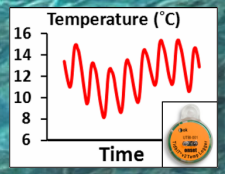

- It's going to continue in significant ways
- Motivated by: climate change, need to understand the effects of habitat restoration, and unknowns regarding species' thermal ecology

## We could be more strategic & efficient

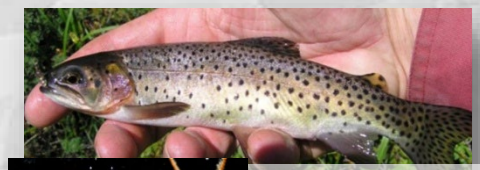
- Better coordination of monitoring efforts within & among agencies
- More timely aggregation & usage of data with customized webtools, semi-automated analyses, & a dedicated database team
- Default alternative: *ad hoc* approach characterized by periodic, opportunistic updates

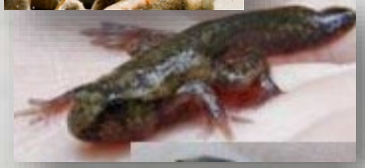






# SSN Models Applicable to More than Stream Temperature Data…

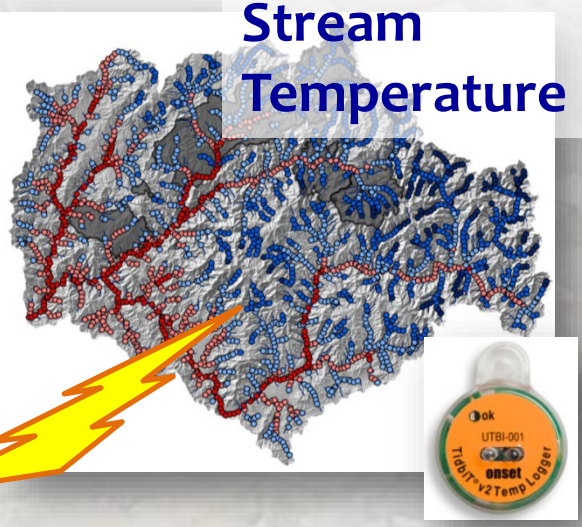


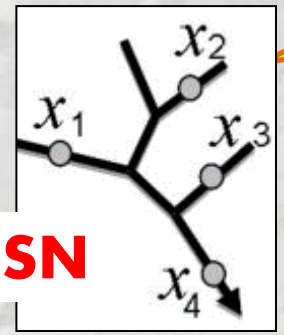


Distribution & abundance

Response Metrics
- Gaussian
- Poissan
- Binomial

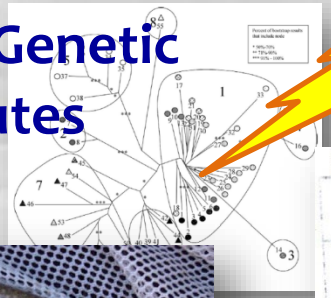
Stream Temperature

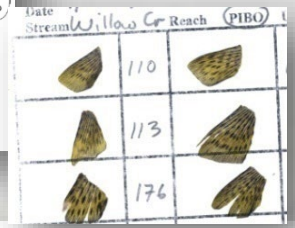


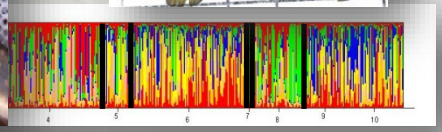




SSN

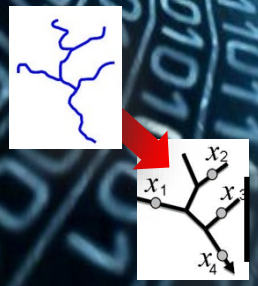
eDNA/Genetic Attributes



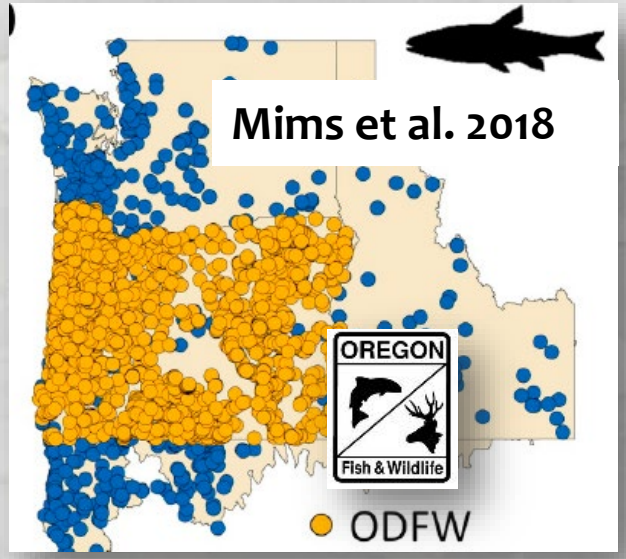


Water Quality Parameters

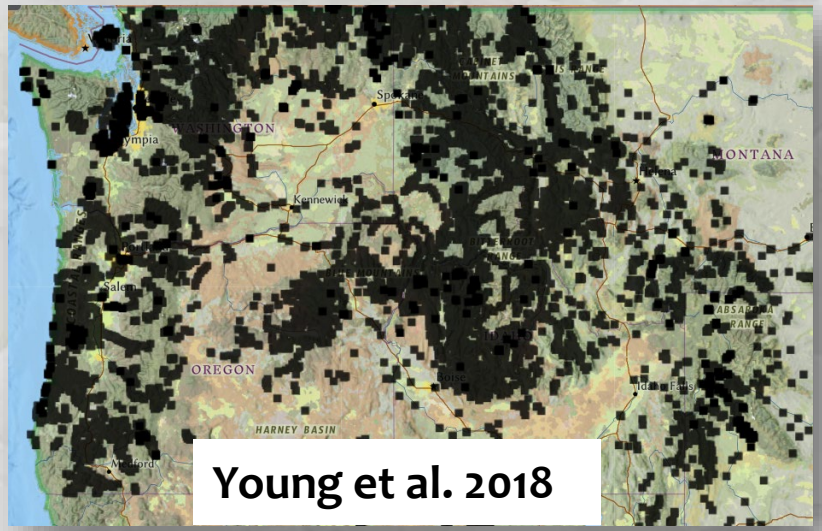


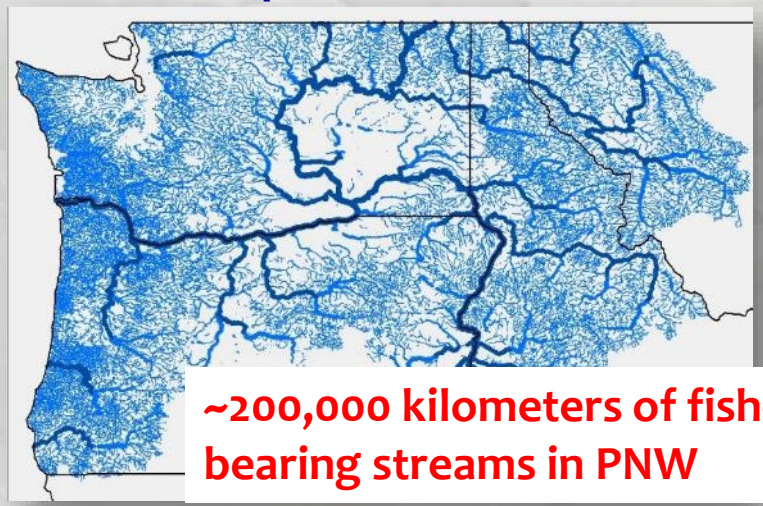
# Large Amounts of Fish Density & Occurrence Data Exist in PNW




Quantifying biophysical relationships from reach-scale observations & extrapolating to networks requires models

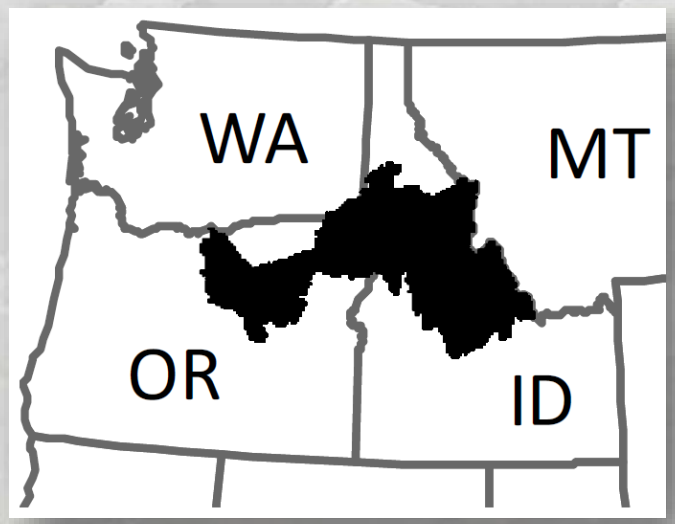
eDNAtlas ~30,000 sample results




**Fish Data Analysis Tool (FDAT) Capitalizes on These Datasets**

# FDAT Example: Modeling Juvenile Chinook Salmon & Steelhead Densities




## Data contributors (2000–2018)

**Table 2.** Sources of juvenile fish density data surveys that were aggregated to create the datasets modeled in this report.

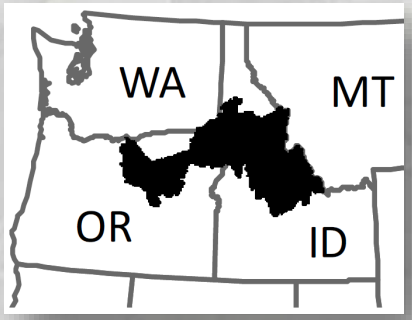
| Species | Data source | Unique stream sites | Site-years of data |
|---|---|---|---|
| Chinook salmon | ODFW | 56 | 100 |
| | FDAT Phase 1 (CRITFC and ODFW) | 131 | 330 |
| | IDFG | 1594 | 5,556 |
| | IDFG - ISEMP | 469 | 682 |
| | BioMark Kevin See | 21 | 23 |
| | U.S. Forest Service[a] | 51 | 66 |
| | Totals: | 2,307 | 6,757 |
| Steelhead | ODFW | 161 | 270 |
| | FDAT Phase 1 (CRITFC and ODFW) | 148 | 366 |
| | IDFG | 1,727 | 5,744 |
| | IDFG – ISEMP | 657 | 937 |
| | BioMark Kevin See | 21 | 23 |
| | U.S. Forest Service[a] | 81 | 96 |
| | Totals: | 2,797 | 7,436 |

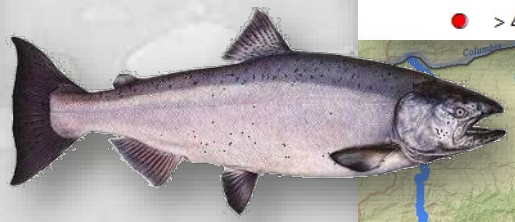
**Funded by:**

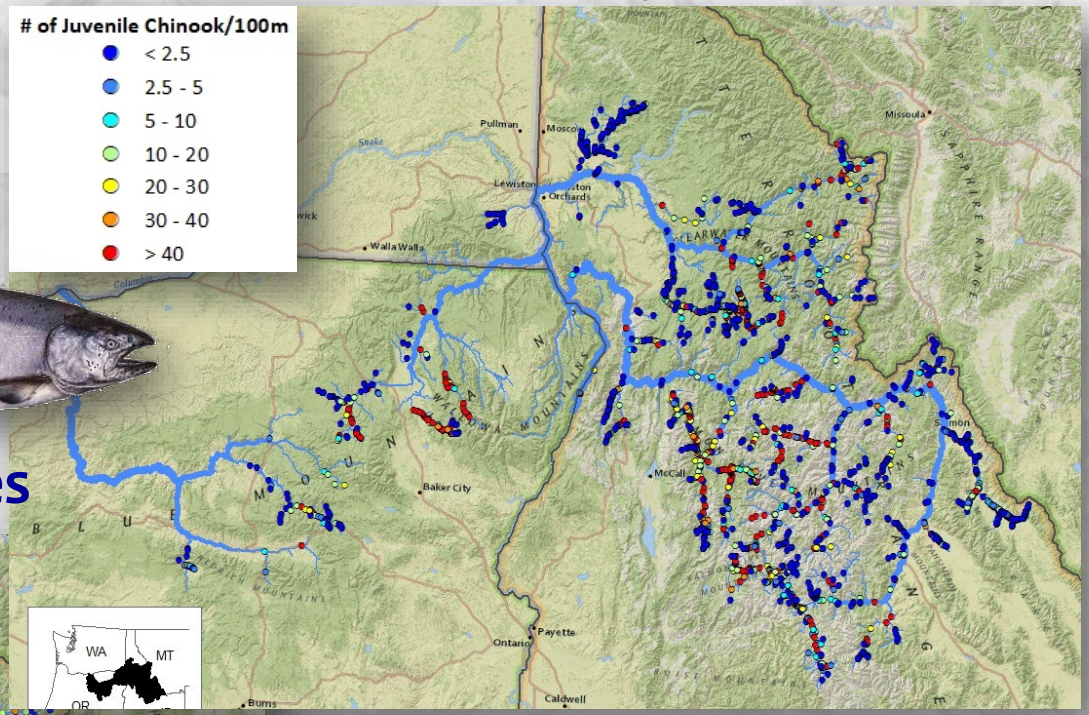
Bonneville POWER ADMINISTRATION

# Juvenile Chinook Salmon & Steelhead Density Datasets

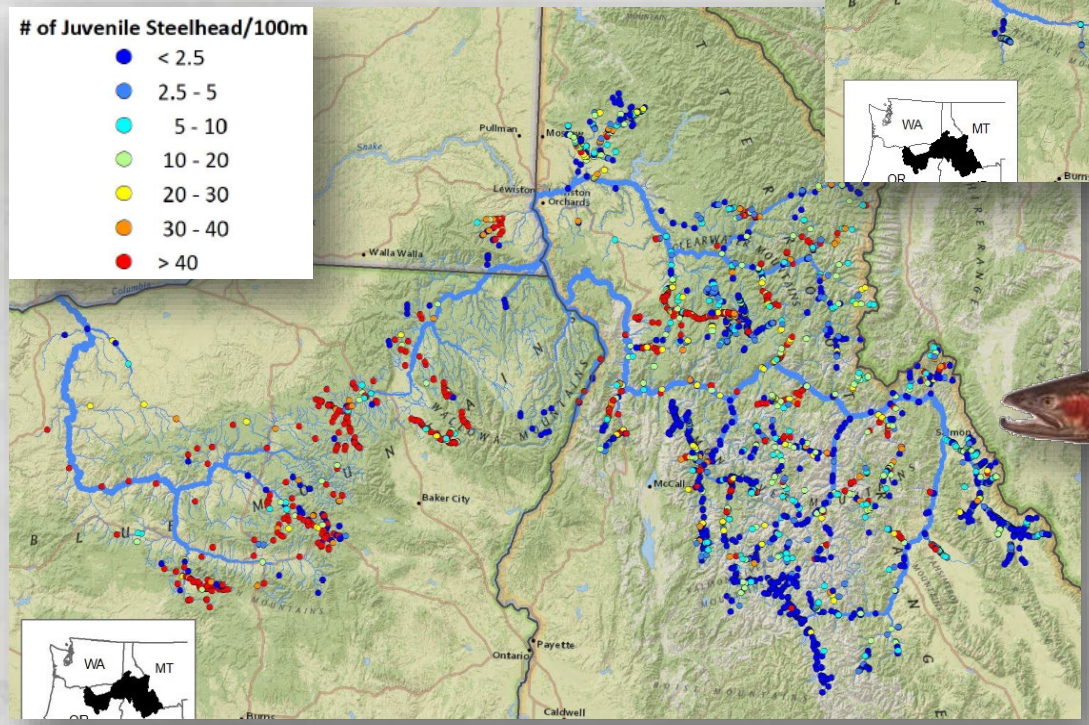
## n = 6,757 surveys at 2,307 sites





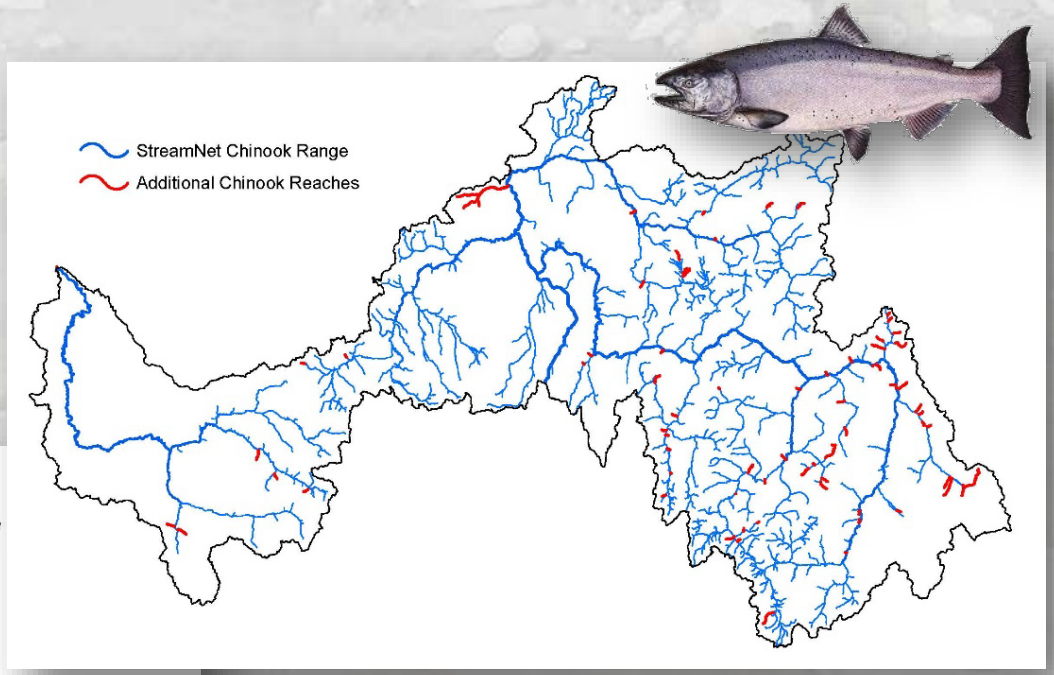

## n = 7,436 surveys at 2,797 sites

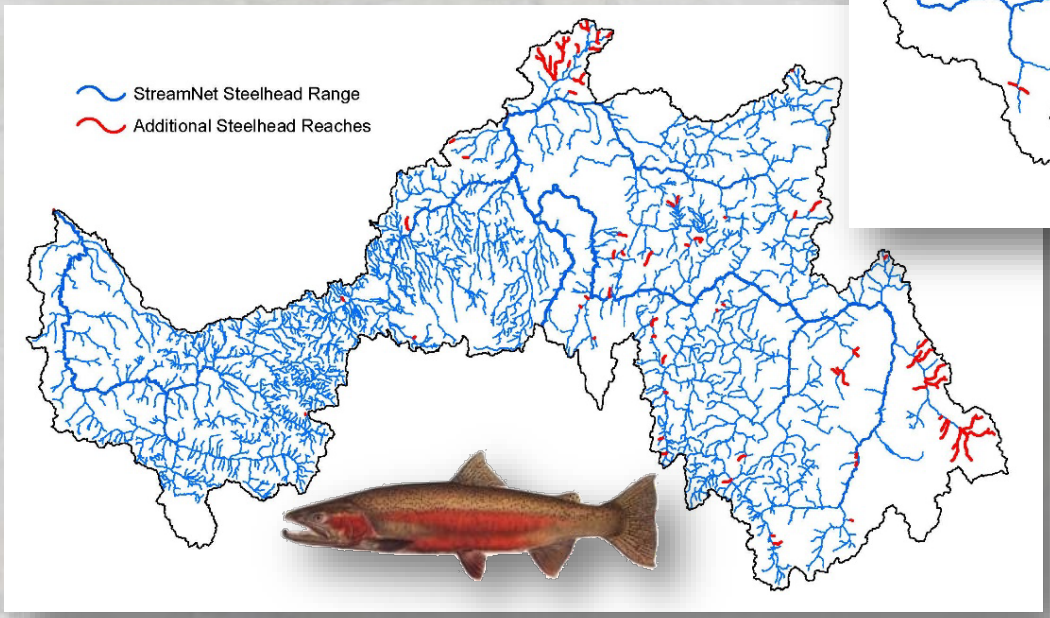



# Potential Habitat Network Extent Delineation

1. StreamNet species reach layers matched to NHD+ reaches
2. Reaches extended upstream if fish data indicated upstream occurrence
3. CRITFC modifications within Grande Ronde basin

- **9,064 km potential habitat network (381 km not in StreamNet)**

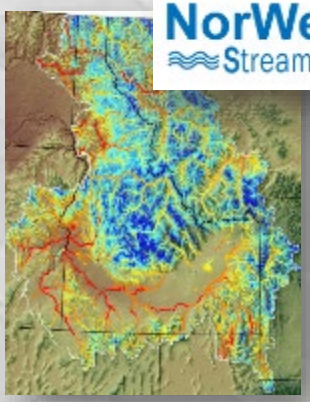



- **18,064 km potential habitat network (580 km not in StreamNet)**

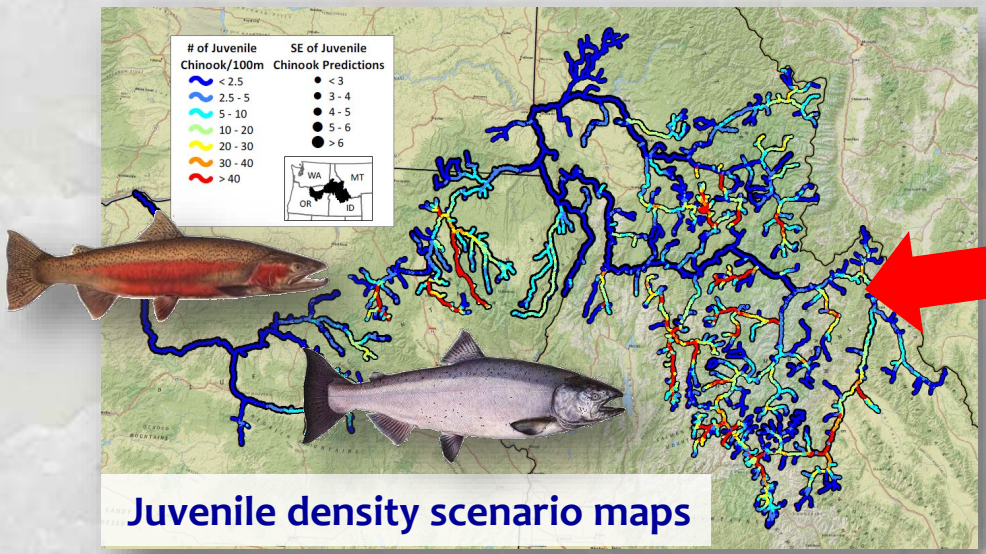
# FDAT Project Modeling Steps for Juvenile Chinook and Steelhead Trout

## n ~ 7,000 density surveys

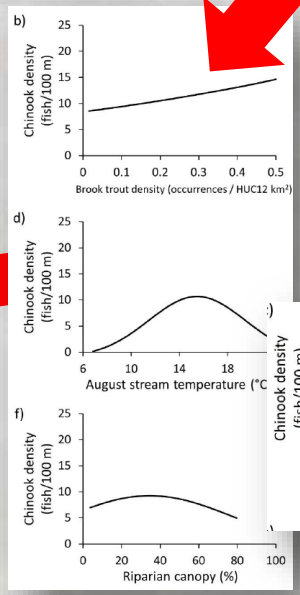

## Additional Covariates

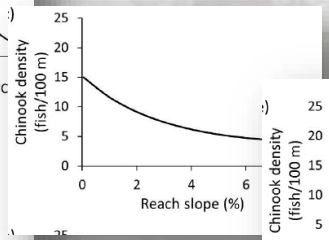
1. Watershed condition
2. Stream flow (cfs)
3. Reach slope (%)
4. Riparian conifer (%)
5. Baseflow Index
6. Brook trout (%)

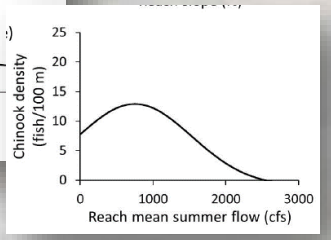



**Juvenile density scenario maps**

## Density Model Response Curves

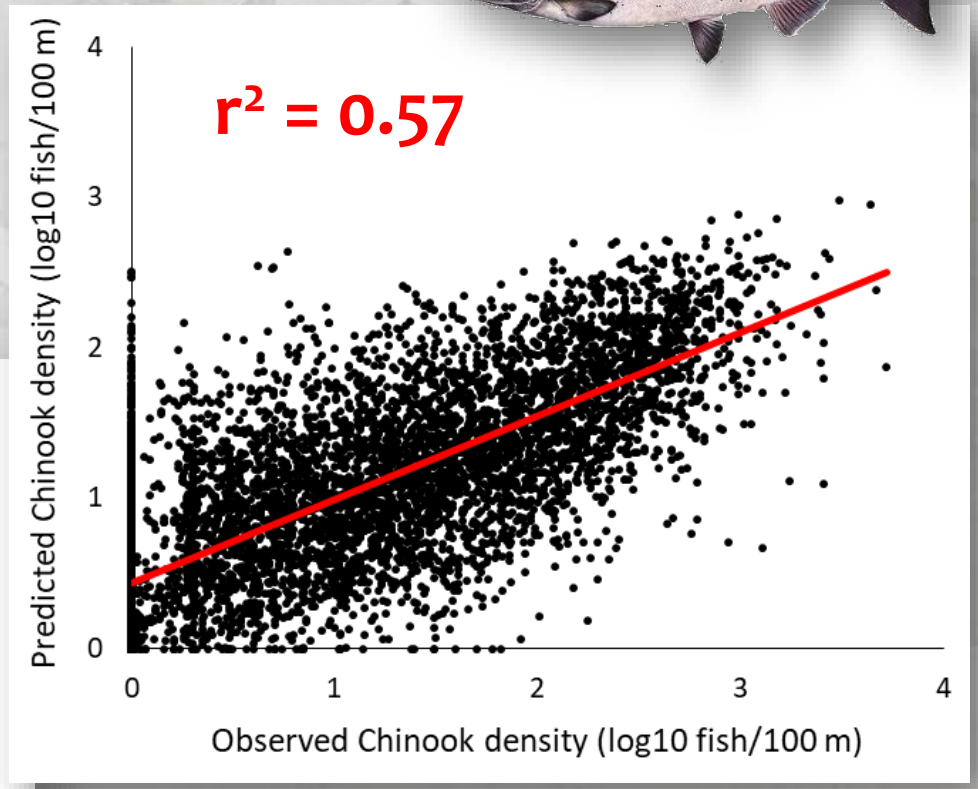


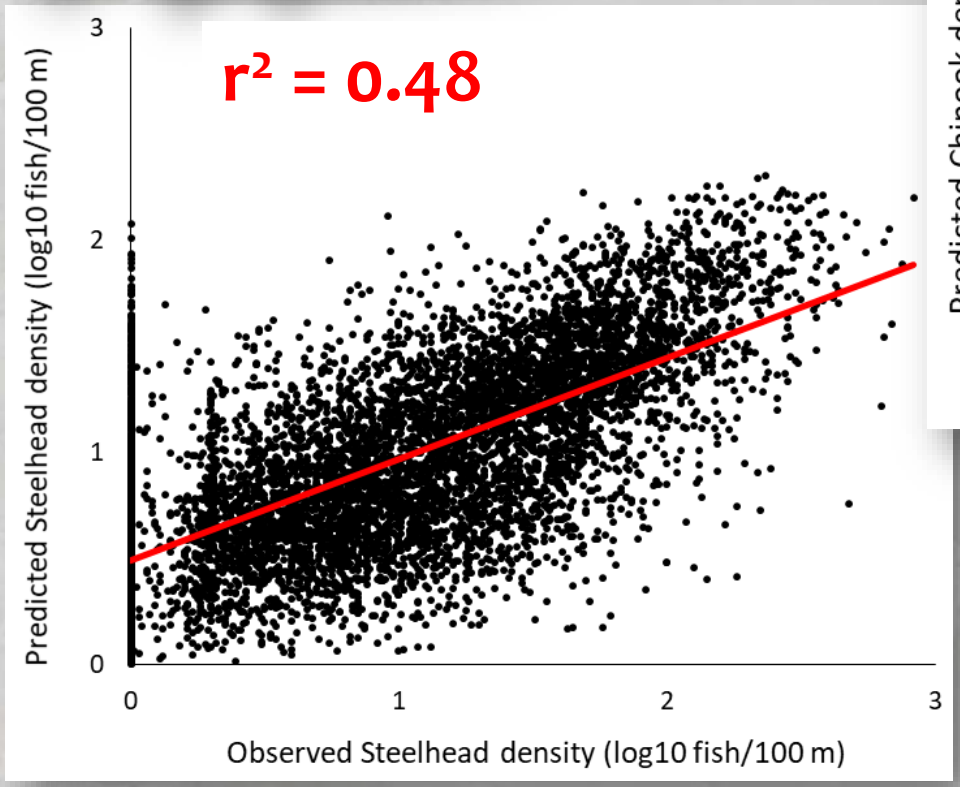




Isaak et al. 2020. Phase 2: Spatial stream network (SSN) analysis for salmonids. Project completion report, Bonneville Power Administration. Portland, OR.

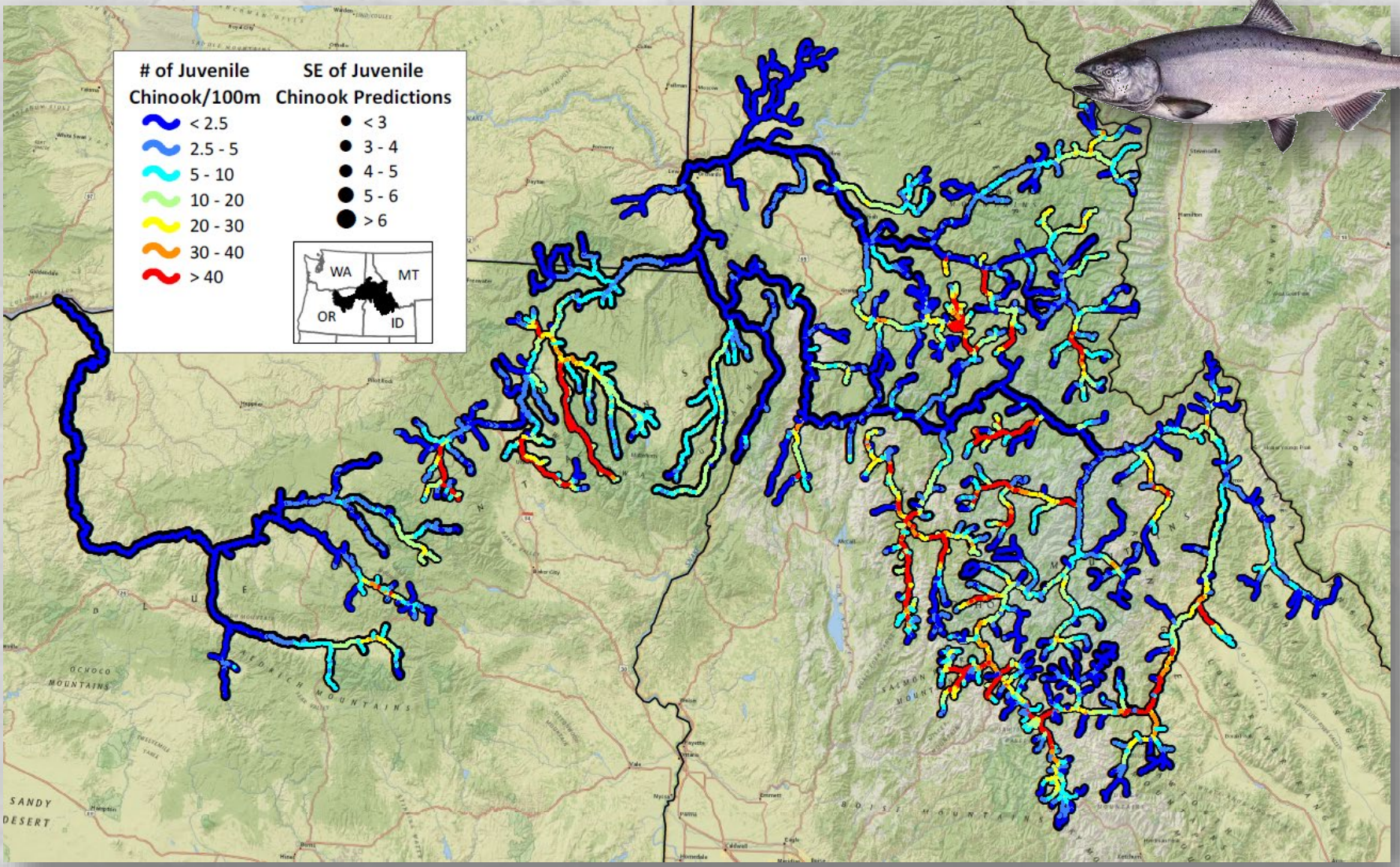
# Predictive Accuracy of SSN Models for Juvenile Densities



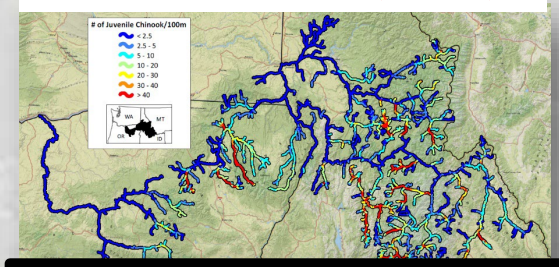
# Juvenile Chinook Salmon Density Map Scenario (Scenario 1: Average densities for 2000–2018)

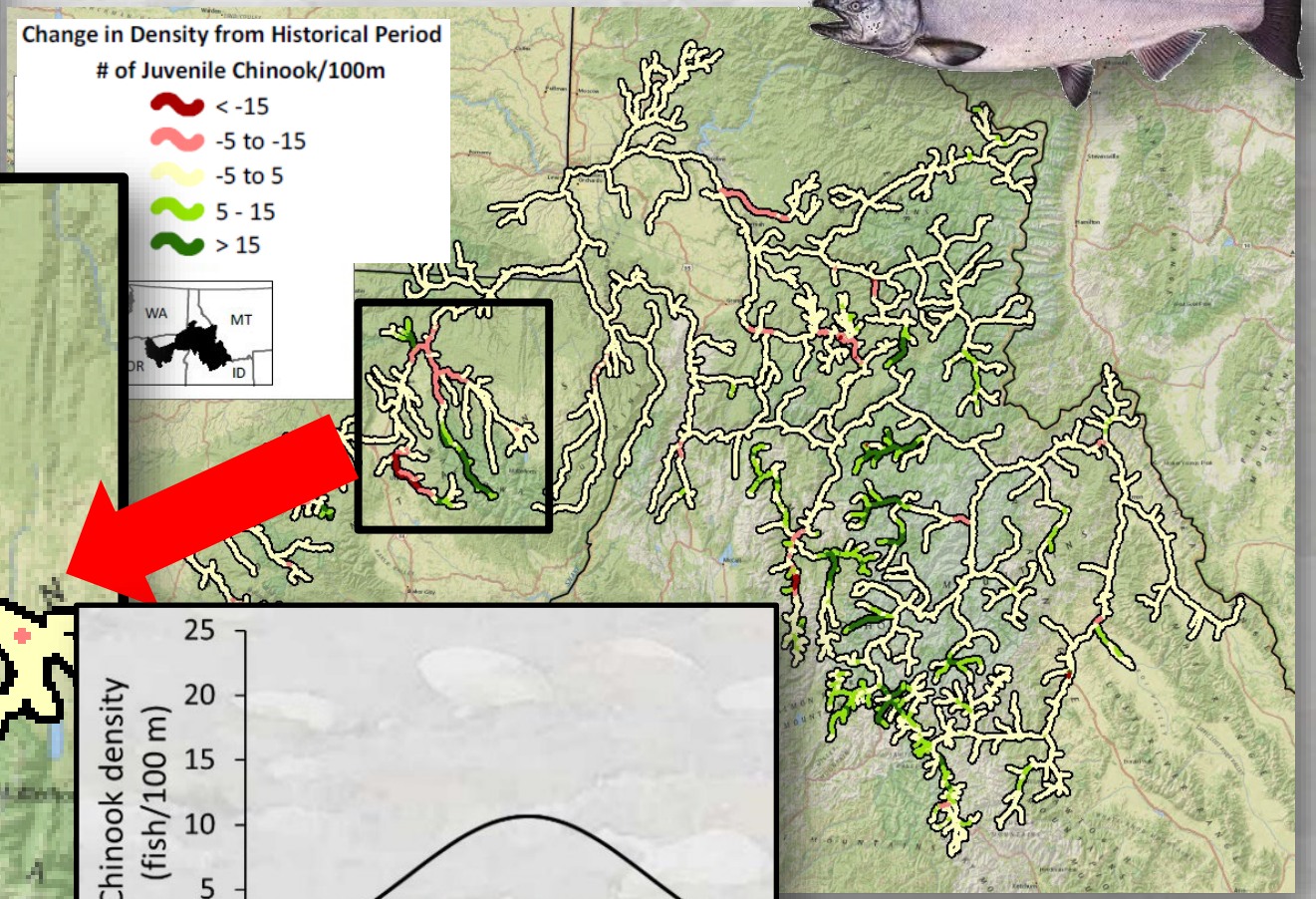
## 24 historical & future scenarios created

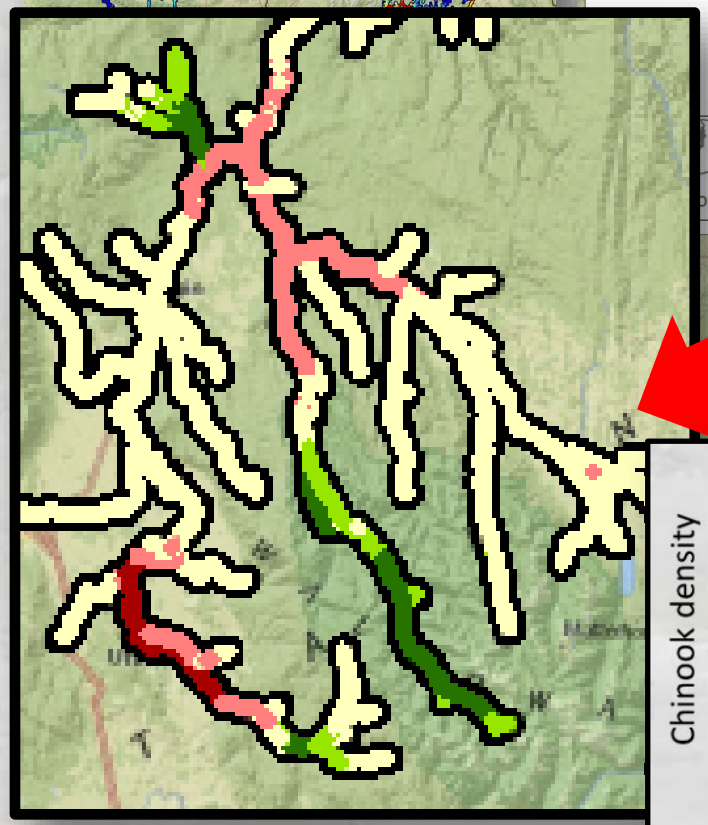


# FDAT Application: Climate Sensitivity Analysis

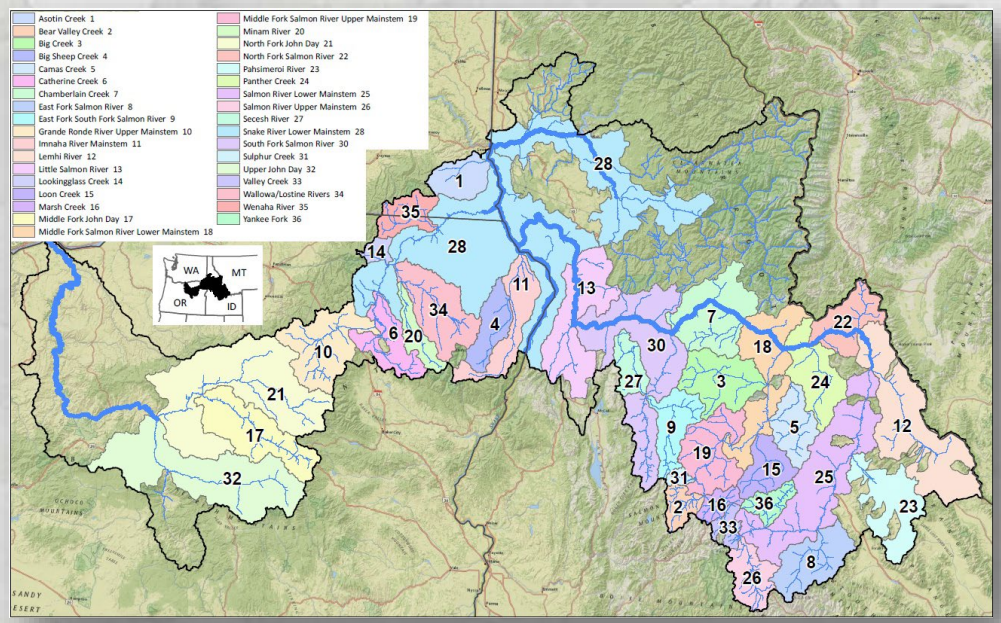
## S23 densities (+2°C)



# FDAT Application: Population estimates & future trends by geographic areas

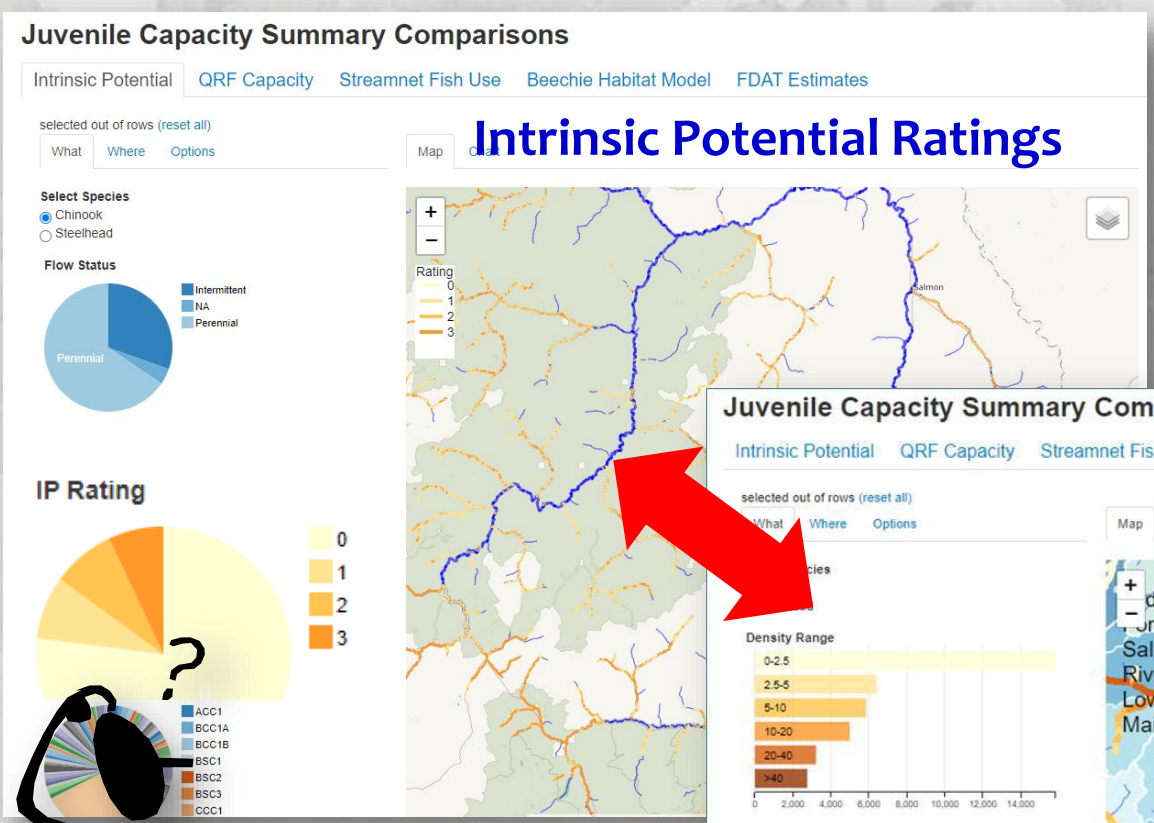


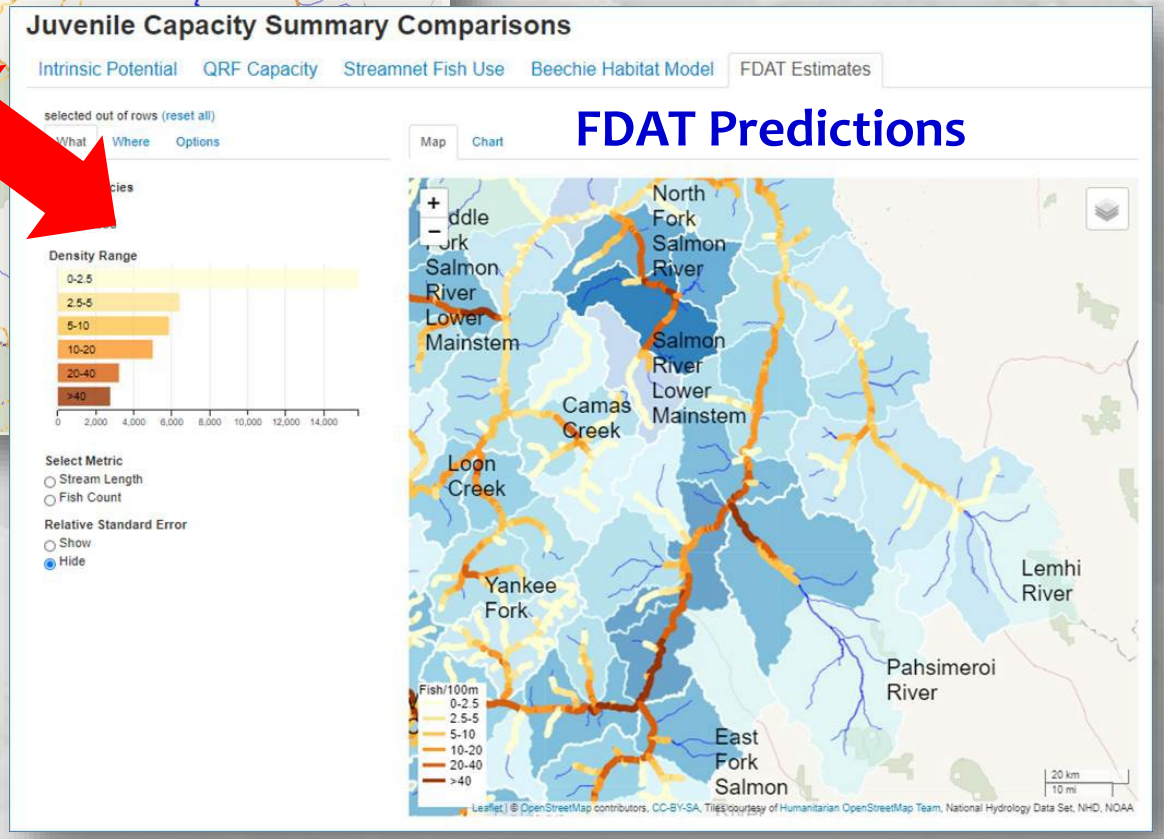

- 9,064 km network
- 35 population areas

**Table 7**. Population estimates and average densities of juvenile Chinook salmon by designated population areas for the baseline scenario (Scenario 1) and a future scenario representing a 2 °C increase in August stream temperatures (Scenario 23).

| Population area name | Habitat network length (km) | Scenario 1 average density (fish / 100 m) | Scenario 1 population estimate |
|---|---|---|---|
| Asotin Creek | 57.8 | 1.33 | 771 |
| Bear Valley Creek | 149 | 30.15 | 44,838 |
| Big Creek | 186 | 24.62 | 45,827 |
| Big Sheep Creek | 79.2 | 7.29 | 5,773 |
| Camas Creek | 138 | 3.54 | 4,896 |
| Catherine Creek | 214 | 36.72 | 78,441 |
| Chamberlain Creek | 241 | 25.68 | 61,788 |
| East Fork Salmon River | 151 | 9.37 | 14,136 |
| East Fork South Fork Salmon River | 174 | 25.87 | 44,929 |

# FDAT Application: Comparison of FDAT Predicted Densities with Intrinsic Habitat Potential




Where are the differences greatest?

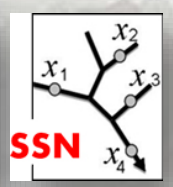
# FDAT Datasets & Statistical Code are Available

- Density scenarios (24) at 250-m resolution available as ArcGIS shapefiles @ the StreamNet data store (https://app.streamnet.org/datastore_search_classic.cfm?id=775&keywords=fish%20data%20analysis%20tools)


- Observed juvenile steelhead & Chinook salmon densities at survey sites (ArcGIS shapefiles)

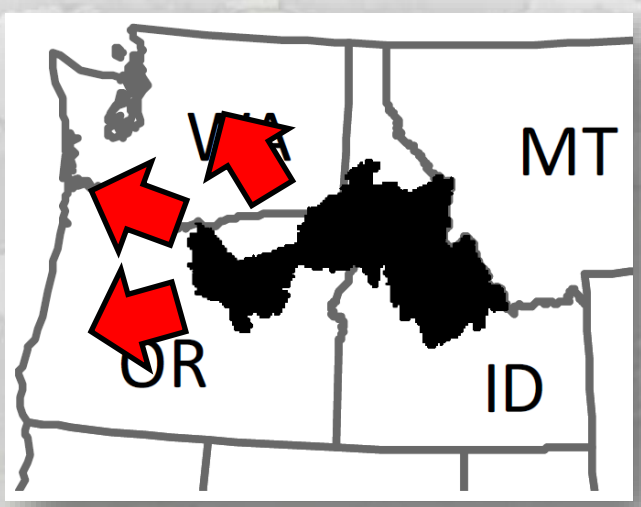
- Digital stream networks of potential habitat/observed occurrences for updating StreamNet species distributions (ArcGIS shapefiles)

- R code & SSN files to replicate analyses

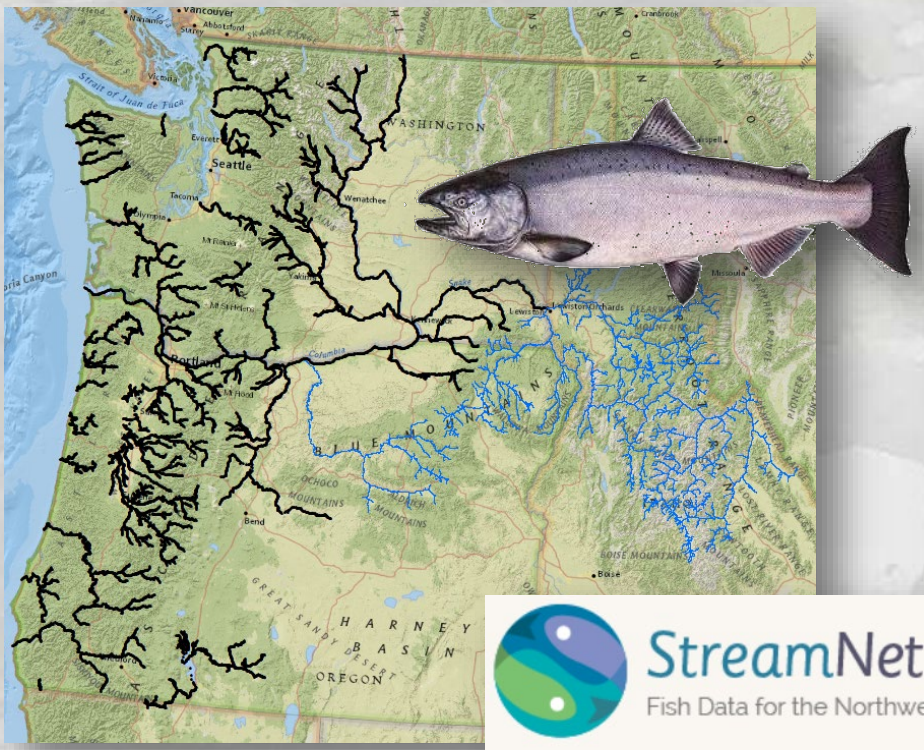

- BPA report describing methods, results, & datasets with a peer-reviewed publication in development for 2024

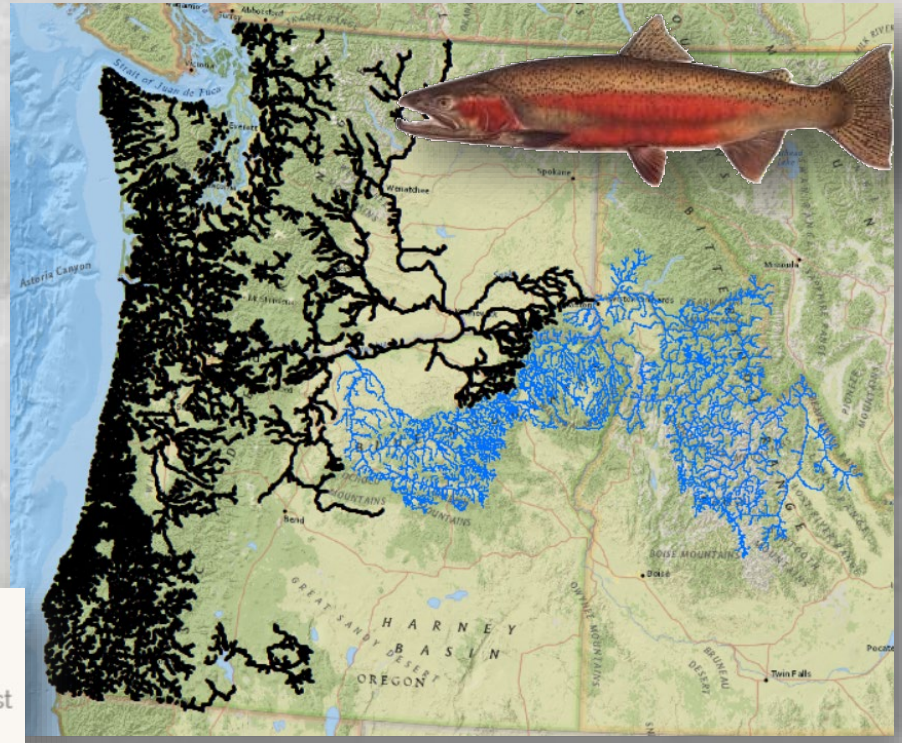
# Next FDAT Phase: Regional Expansion is Underway




## Major Objectives:

1) Expand FDAT datasets & prediction scenarios for consistency throughout PNW anadromous streams
2) Develop pilot application with bull trout
3) Develop a consistent data exchange standard for reporting density information

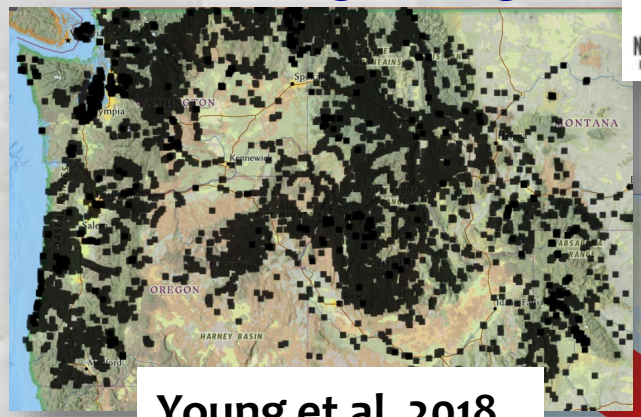



StreamNet
Fish Data for the Northwest

# FDAT Architecture Adaptable to Many Species Using Legacy Datasets or Recent eDNA Survey Results

eDNAtlas ~30,000 sample results (& growing)

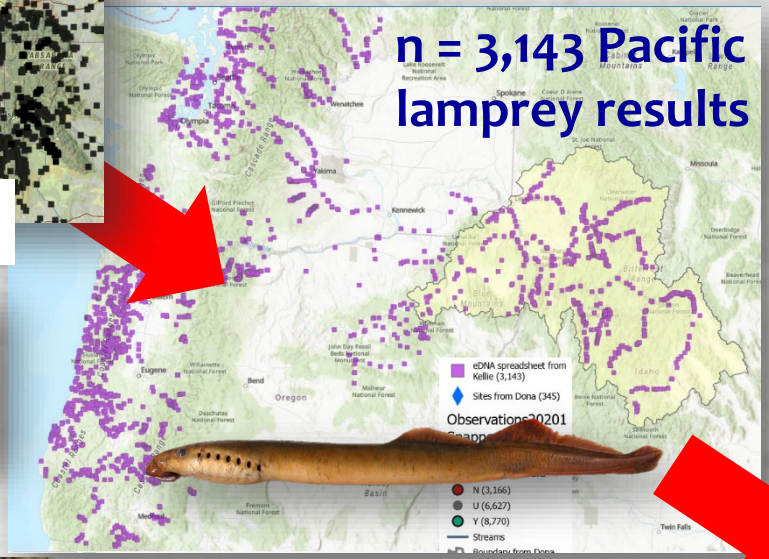



Young et al. 2018

National Genomics Center
FOR WILDLIFE AND FISH CONSERVATION

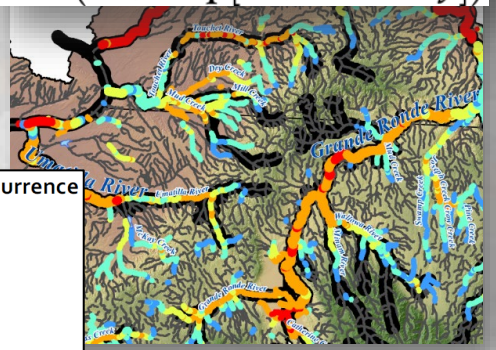
Many agencies

Guidance for habitat restoration locations



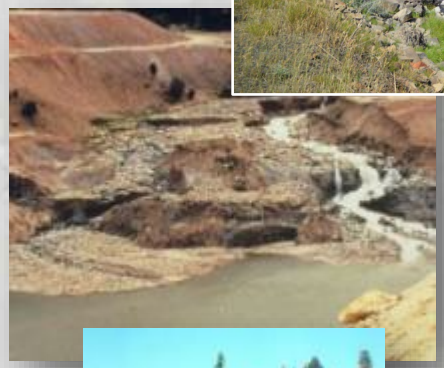

Species distribution models and scenarios

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




Guidance for refined field sampling campaigns

# **Ultimate Goal:** Better Information to Guide Restoration & Conservation Investments



## Many options:

1) Improve riparian function & shade
2) Increase summer flow volumes
3) Restore channel complexity & floodplain connections
4) Minimize habitat fragmentation
5) Control invasive species

**Where to do them?**

**How to maximize bang for the**

**Strategic Investing is Key**


The End
Questions?

# Applications Continue Growing…

## Website bibliography listed 30 projects as of 2022

### NorWeST data applications

Climate-shield cold-water refuges for native trout website: **https://www.fs.fed.us/rm/boise/AWAE/projects/ClimateShield.**

The rangewide bull trout eDNA project website: **https://www.fs.fed.us/rm/boise/rm/boise/AWAE/projects/BullTrout_eDN**

Al-Chokhachy, R., D. Schmetterling, C. Clancy, P. Saffel, R. Kovach, L. Nyce, B. Liermann, W. Fredenberg, and R. Pierce. 201 **displacing bull trout populations in a changing climate?** Canadian Journal of Fisheries and Aquatic Science 73: doi.org/10.

Asarian, J.E. 2017. **GIS Stream Temperature Modeling of Yurok Ancestral Territory**. Prepared by Riverbend Sciences for t Program, Klamath, CA. 39 p. [**electronic appendices**]

Dauwalter, D.C., K.A. Fesenmyer, and R. Bjork. 2015. **Using aerial imagery to characterize redband trout habitat in a remote desert landscape.** Transactions of the American Fisheries Society 144:1322-1339.

Dunham, J., D. Hockman-Wert, N. Chelgren, and M. Heck. 2015. **Rangewide climate vulnerability assessment for threatened Bull Trout.** Final report submitted to Department of Interior, Northwest Climate Science Center, Corvallis, OR. *[other resources]*

EcoAdapt. 2014. **A climate change vulnerability assessment for resources of Nez-Perce Clearwater National Forests.** Version 3.0. EcoAdapt, Bainbridge Island, WA.

Howell PJ. 2017. **Changes in native bull trout and non-native brook trout distributions in the upper Powder River basin after 20 years, relationships to water temperature and implications of climate change**. Ecology of Freshwater Fish. **https://doi.org/10.1111/eff.12386**

Isaak, D.J., M.K. Young, D. Nagel, D. Horan, and M. Groce. 2015. **The coldwater climate shield: Delineating refugia to preserve salmonid fishes through the 21st Century**. Global Change Biology 21:2540-2553.

Isaak, D.J., K. Ramsey, J. Chatel, D. Konnoff, R. Gecy, and D. Horan. 2016. **Climate change, fish, and aquatic habitat in the Blue Mountains.** Pages x-x in Halofsky, J.E.; Peterson, D.L., eds. 2016. Climate change vulnerability and adaptation in the Blue Mountains. Gen. Tech. Rep. PNW-GTR-xxx. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Isaak, Daniel J.; Ver Hoef, Jay M.; Peterson, Erin E.; Horan, Dona L.; Nagel, David E. 2017. **Scalable population estimates using spatial-stream-network (SSN) models, fish density surveys, and national geospatial database frameworks for streams.** Canadian Journal of Fisheries and Aquatic Sciences. 74: 147-156.