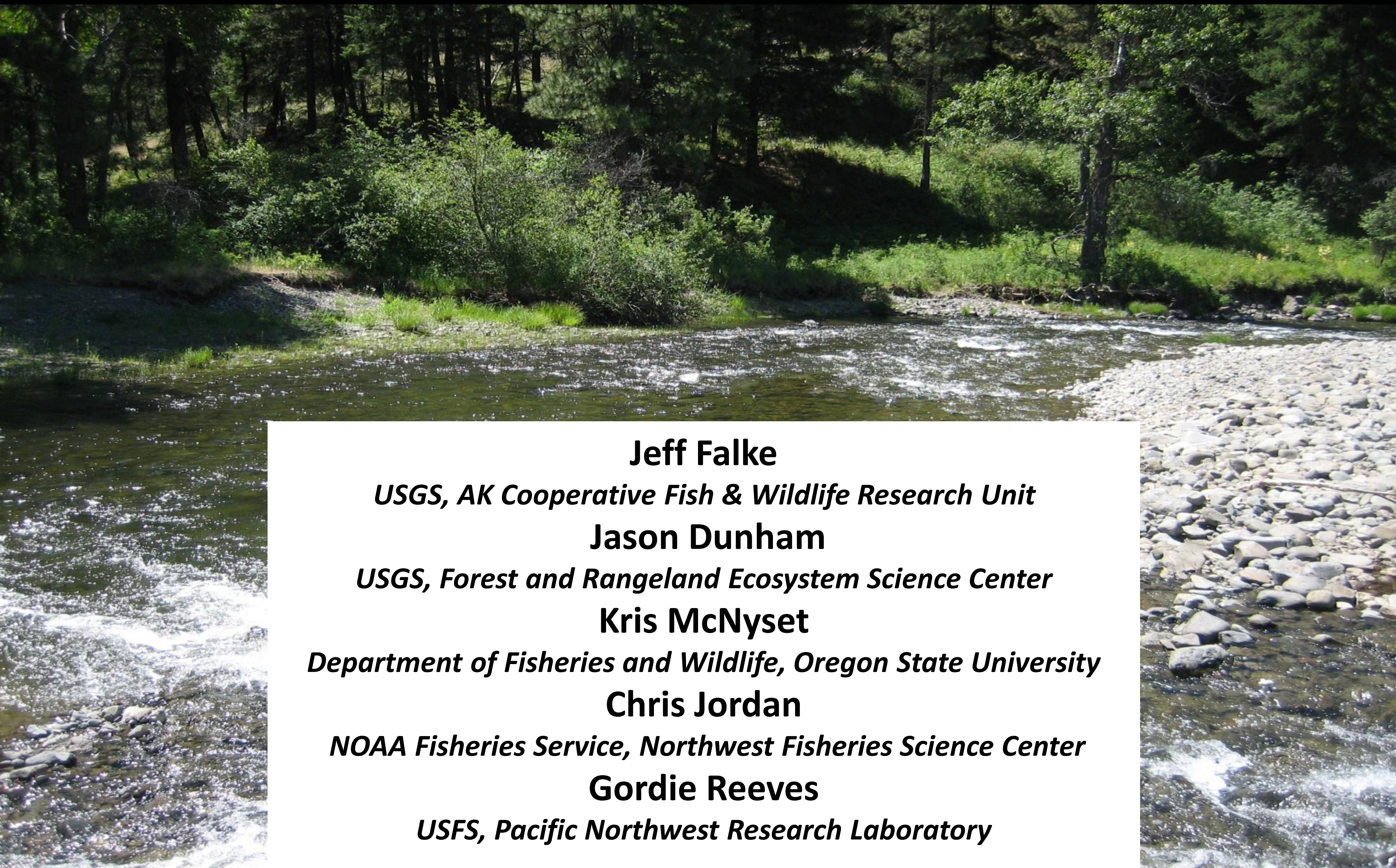
Steelhead in space: integrating spatial ecological processes into stream fish conservation and management



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Spatial Ecological Processes and Local Factors Predict the Distribution and Abundance of Spawning by Steelhead (*Oncorhynchus mykiss*) across a Complex Riverscape

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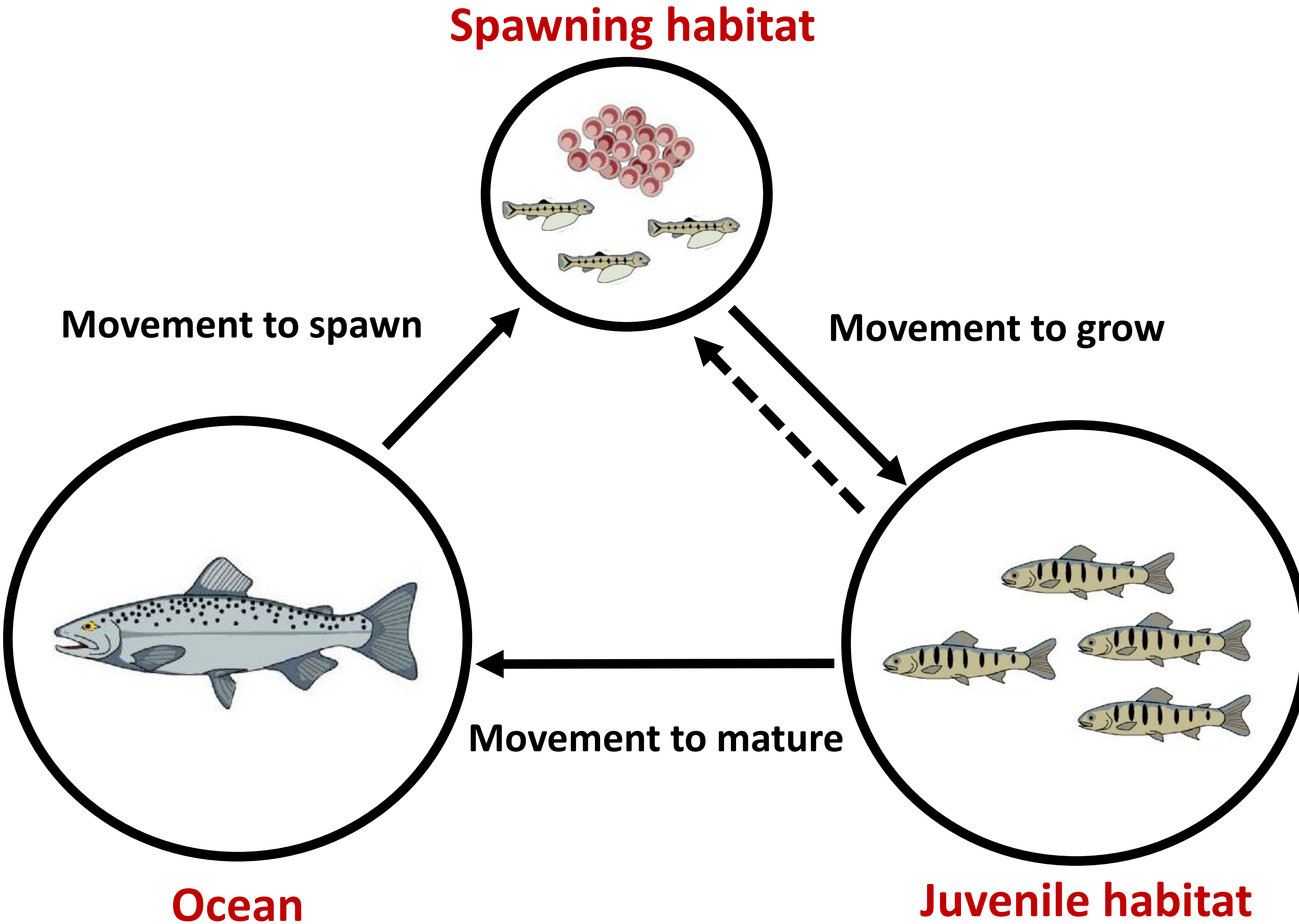
Abstract

Processes that influence habitat selection in landscapes involve the interaction of habitat composition and configuration and are particularly important for species with complex life cycles. We assessed the relative influence of landscape spatial processes and local habitat characteristics on patterns in the distribution and abundance of spawning steelhead (*Oncorhynchus mykiss*), a threatened salmonid fish, across ~15,000 stream km in the John Day River basin, Oregon, USA. We used hurdle regression and a multi-model information theoretic approach to identify the relative importance of covariates representing key aspects of the steelhead life cycle (e.g., site access, spawning habitat quality, juvenile survival) at two spatial scales: within 2-km long survey reaches (local sites) and ecological neighborhoods (5 km) surrounding the local sites. Based on Akaike's Information Criterion, models that included covariates describing ecological neighborhoods provided the best description of the distribution and abundance of steelhead spawning given the data. Among these covariates, our representation of offspring survival (growing-season-degree-days, °C) had the strongest effect size (7x) relative to other predictors. Predictive performances of model-averaged composite and neighborhood-only models were better than a site-only model based on both occurrence (percentage of sites correctly classified = 0.80±0.03 SD, 0.78±0.02 vs. 0.62±0.05, respectively) and counts (root mean square error = 3.37, 3.93 vs. 5.57, respectively). The importance of both temperature and stream flow for steelhead spawning suggest this species may be highly sensitive to impacts of land and water uses, and to projected climate impacts in the region and that landscape context, complementation, and connectivity will drive how this species responds to future environments.

Citation: Falke JA, Dunham JB, Jordan CE, McNyset KM, Reeves GH (2013) Spatial Ecological Processes and Local Factors Predict the Distribution and Abundance

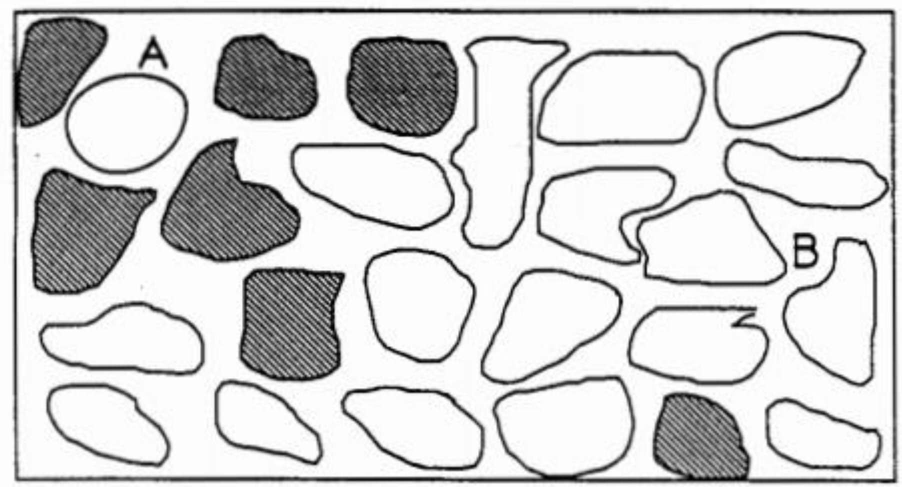
Complex Life Cycles and Multiple Habitat Types



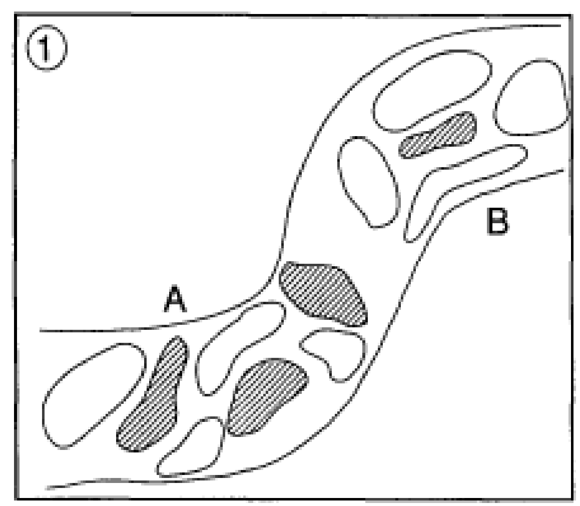
Northcote (1978); Schlosser and Angermeier (1995)

Spatial Ecological Processes

Habitat complementation = "Spatial proximity of non-substitutable habitat types"



Dunning et al. (1992)



Schlosser (1995)

<u>Expectations:</u>

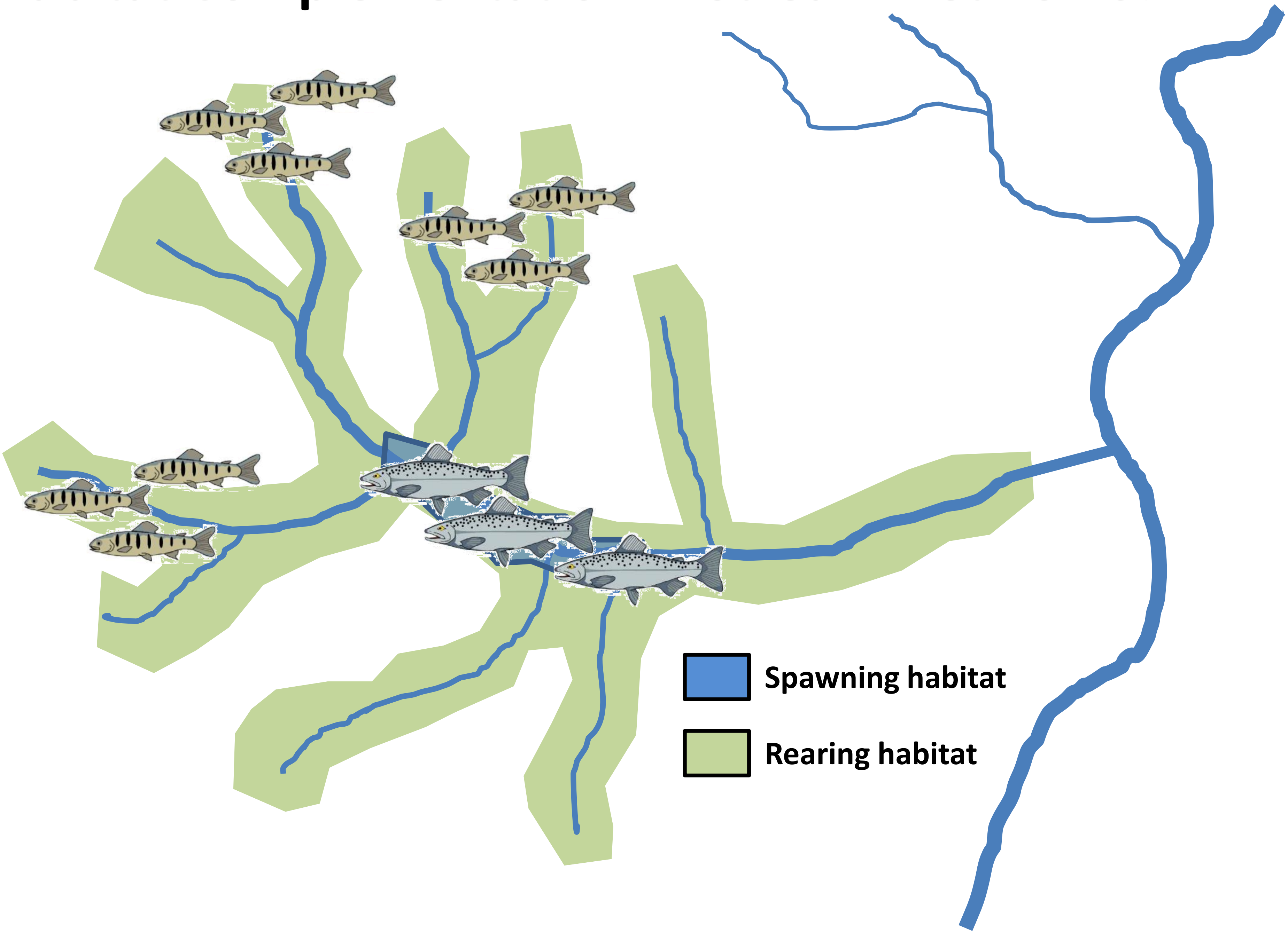
1. ⬇ Energetic dispersal cost =

⬆ Growth and survival

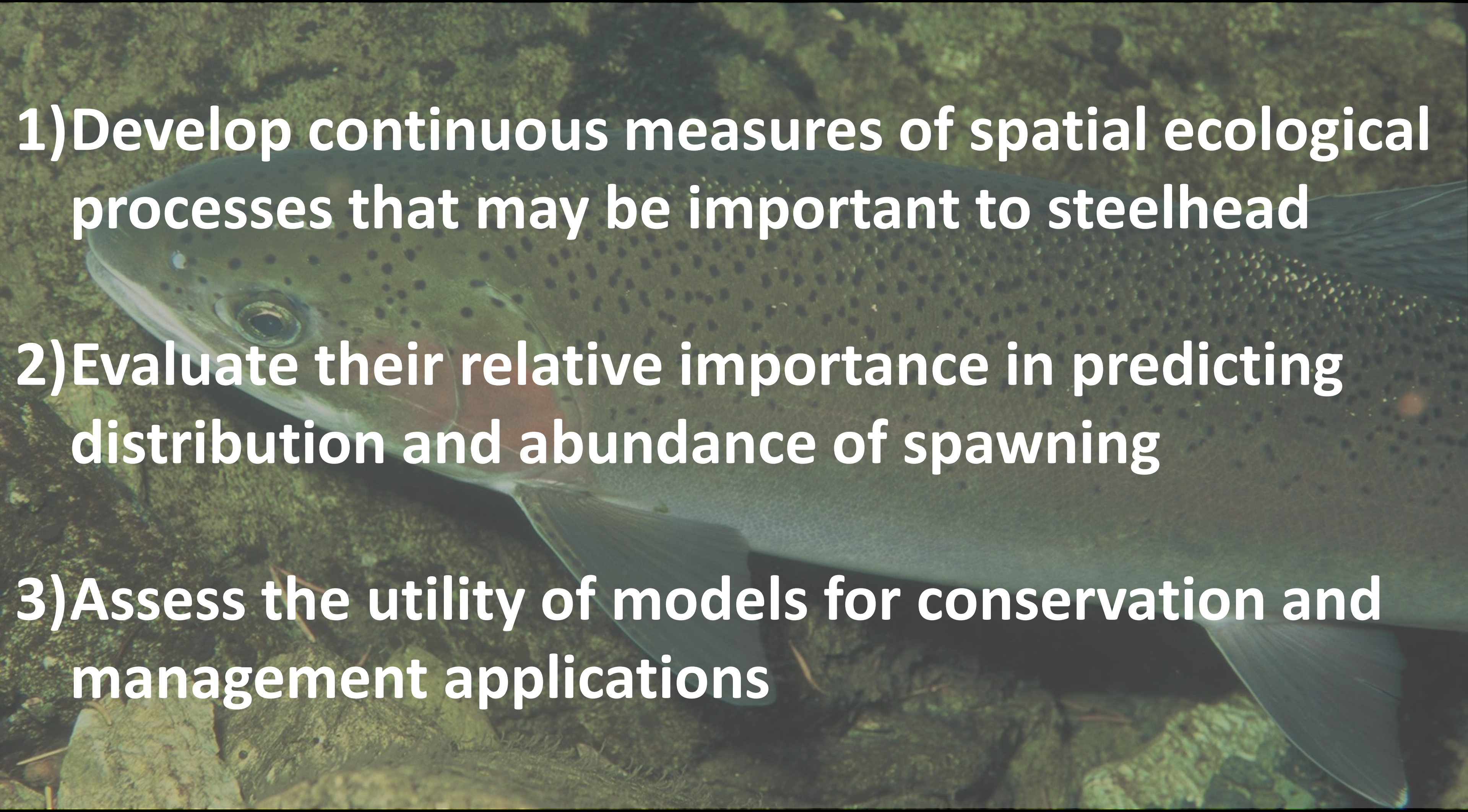
2. ⬇ Travel time =

⬇ Predation mortality

Habitat Complementation in Stream Networks?



Objectives

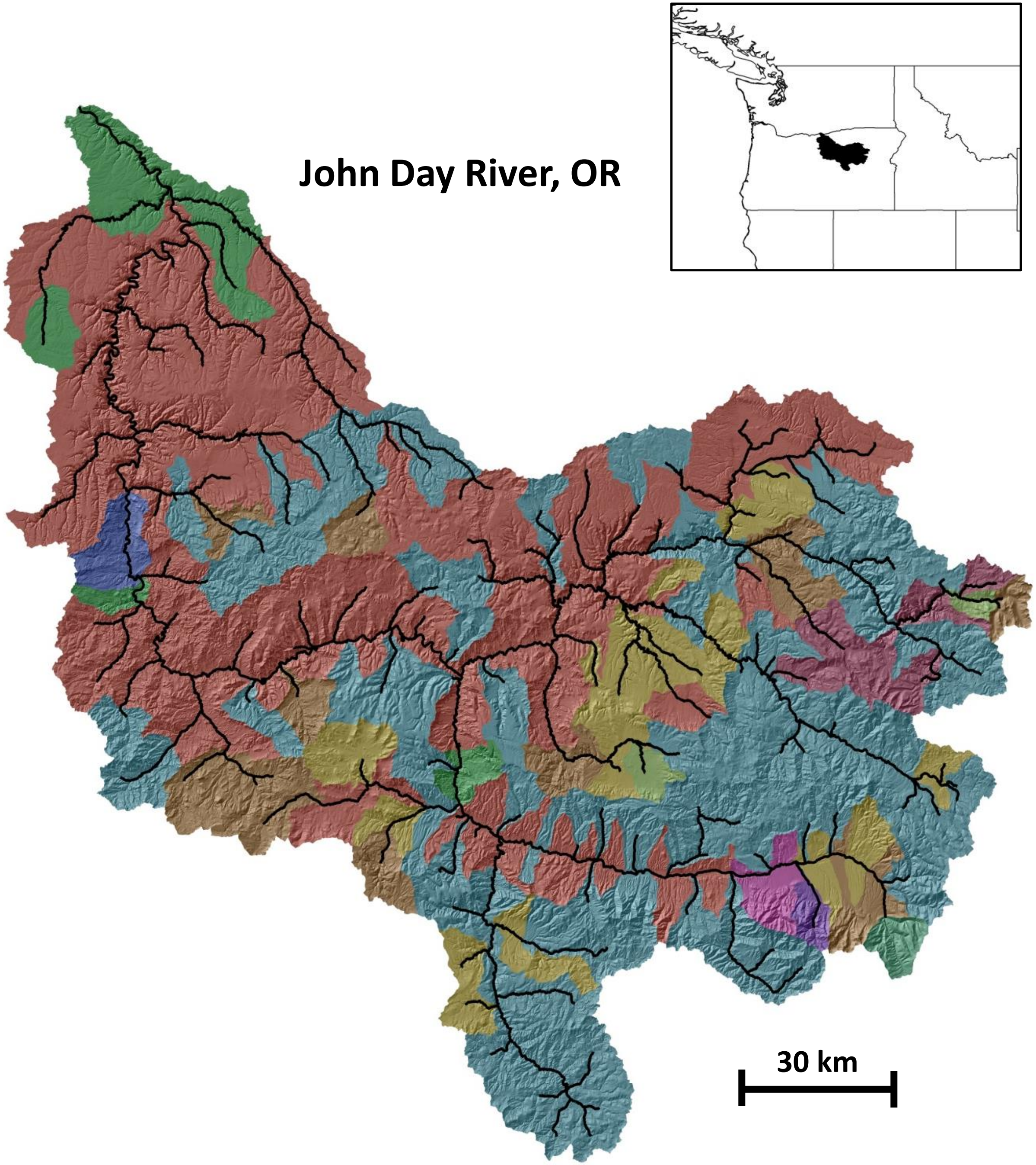


1) Develop continuous measures of spatial ecological processes that may be important to steelhead

2) Evaluate their relative importance in predicting distribution and abundance of spawning

3) Assess the utility of models for conservation and management applications

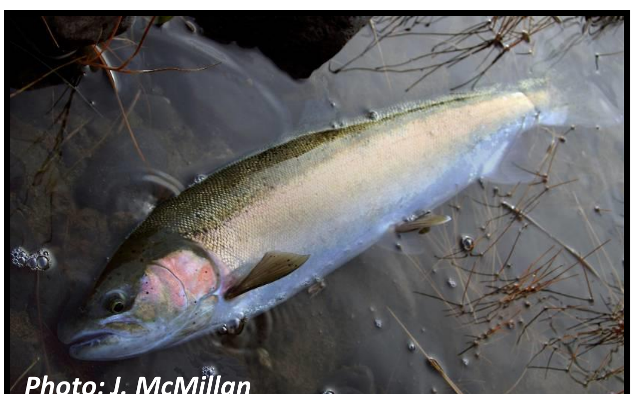
Study Area

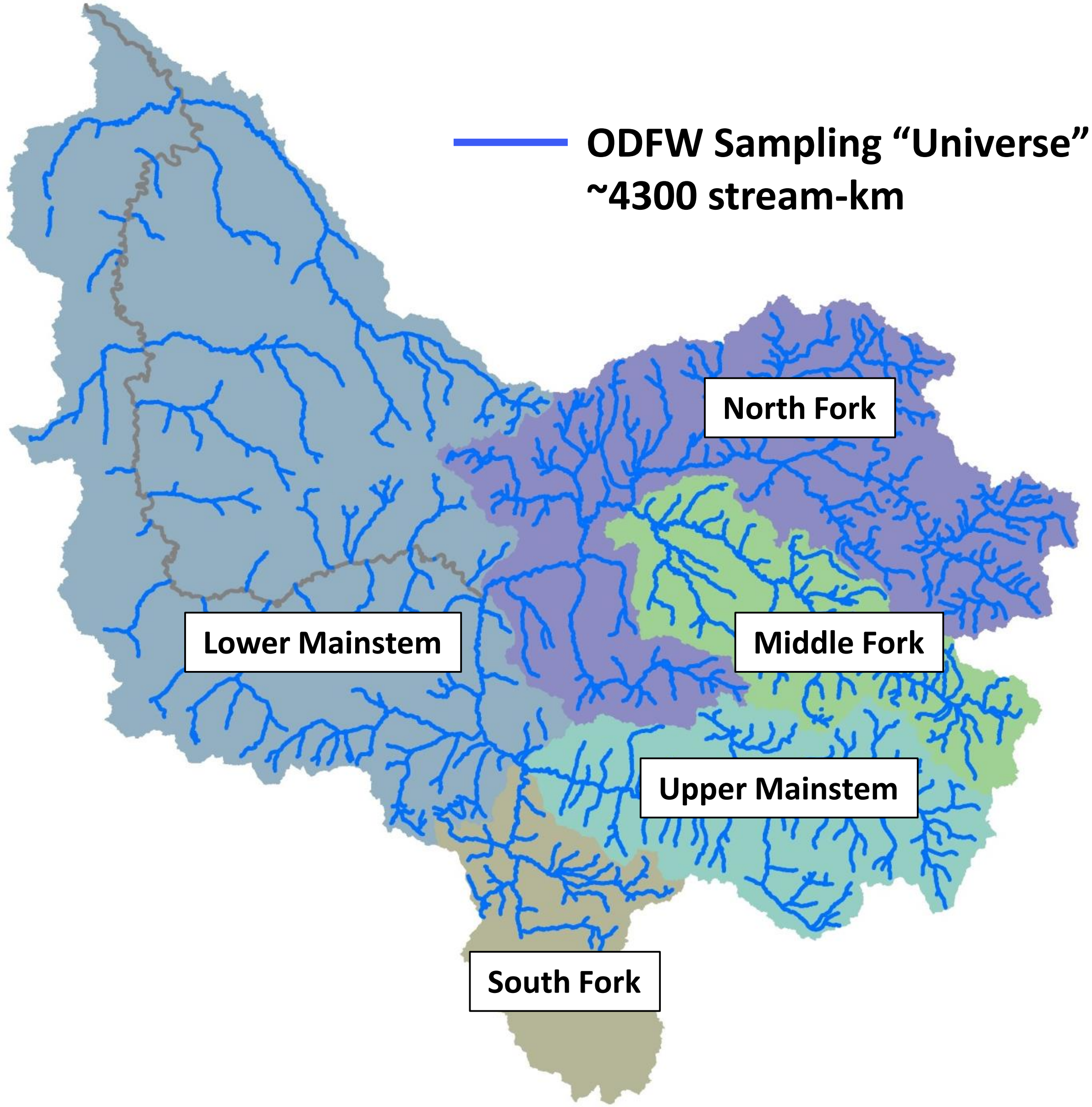


PNW Natural Features Classification (T. Whittier, OSU)

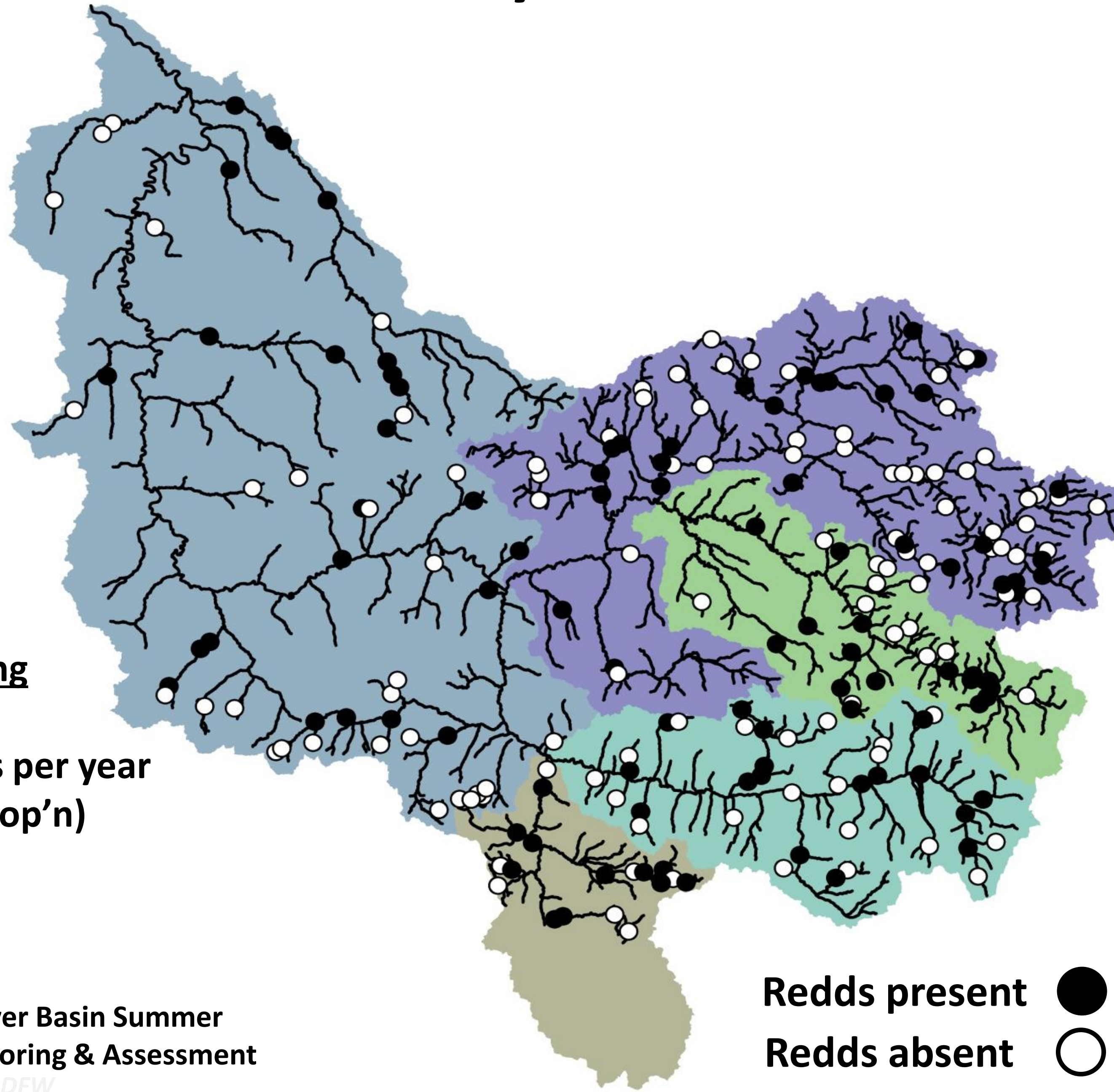
John Day Steelhead

(*O. mykiss gairdnerii*)





John Day Steelhead Redd Survey Data



Status and Trend Monitoring

- **2004-2010**
- **Fifty - 2 km long surveys per year**
- ***N* = 209 sites (~10% of pop'n)**

Response

- **Presence/Absence**
- **Maximum Count**

***Data courtesy ODFW John Day River Basin Summer Steelhead Environmental Monitoring & Assessment Program**

Photo: ODFW

Steelhead Freshwater Life-Cycle: Key Processes

1) Adult survival and spawning habitat accessibility

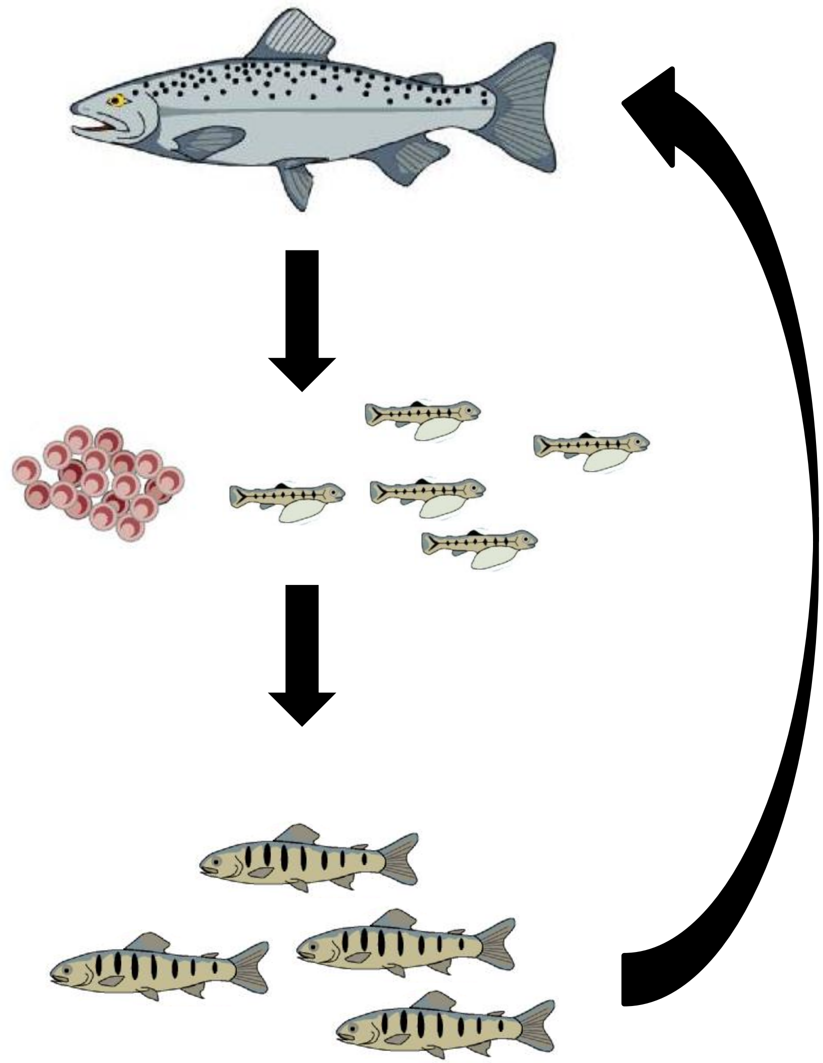
- Stream size
- Energetic cost

2) Spawning success

- Substrate suitability
- Scour likelihood

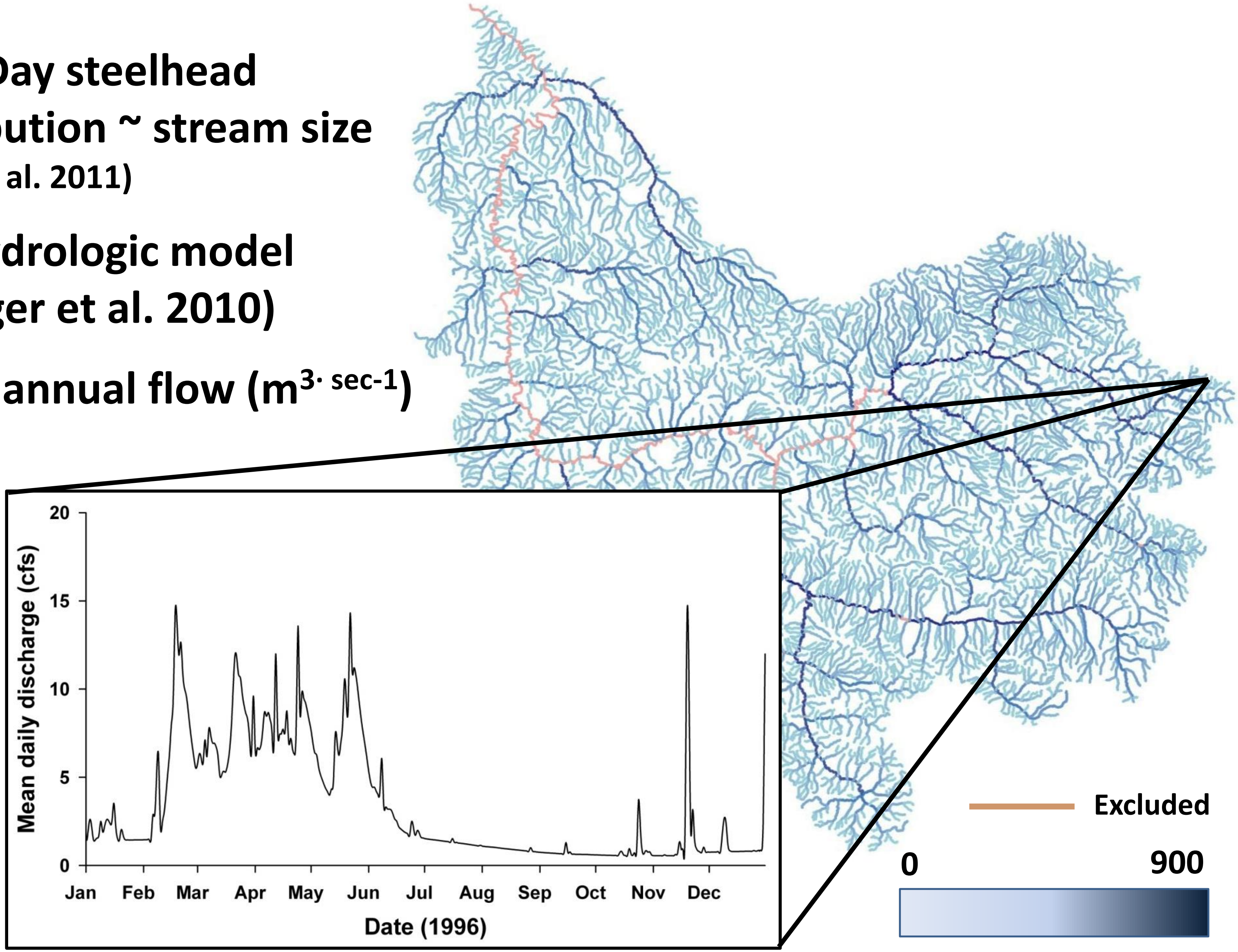
3) Juvenile growth and survival

- Thermal regime



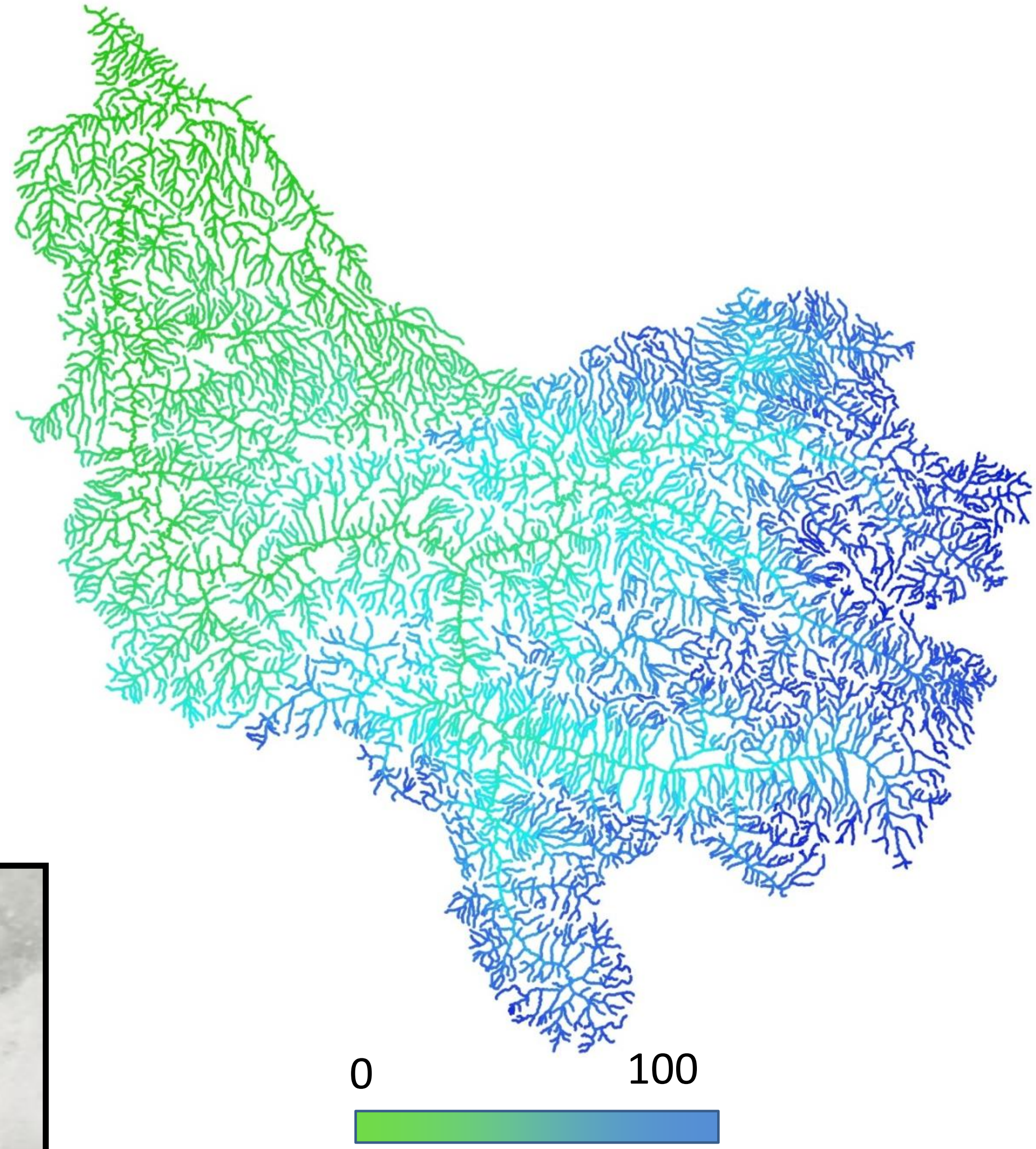
Survival and Access—Stream size

- **John Day steelhead distribution ~ stream size** (Mills et al. 2011)
- **VIC hydrologic model (Wenger et al. 2010)**
- **Mean annual flow ($m^{3} \cdot sec^{-1}$)**



Survival and Access—Energetic cost

- **Energetic "work"** **(Hinch et al. 1996; Crossin et al. 2004)**
- **Distance to outlet (km) x elevation (m)**
- **Travel time, range of velocities**



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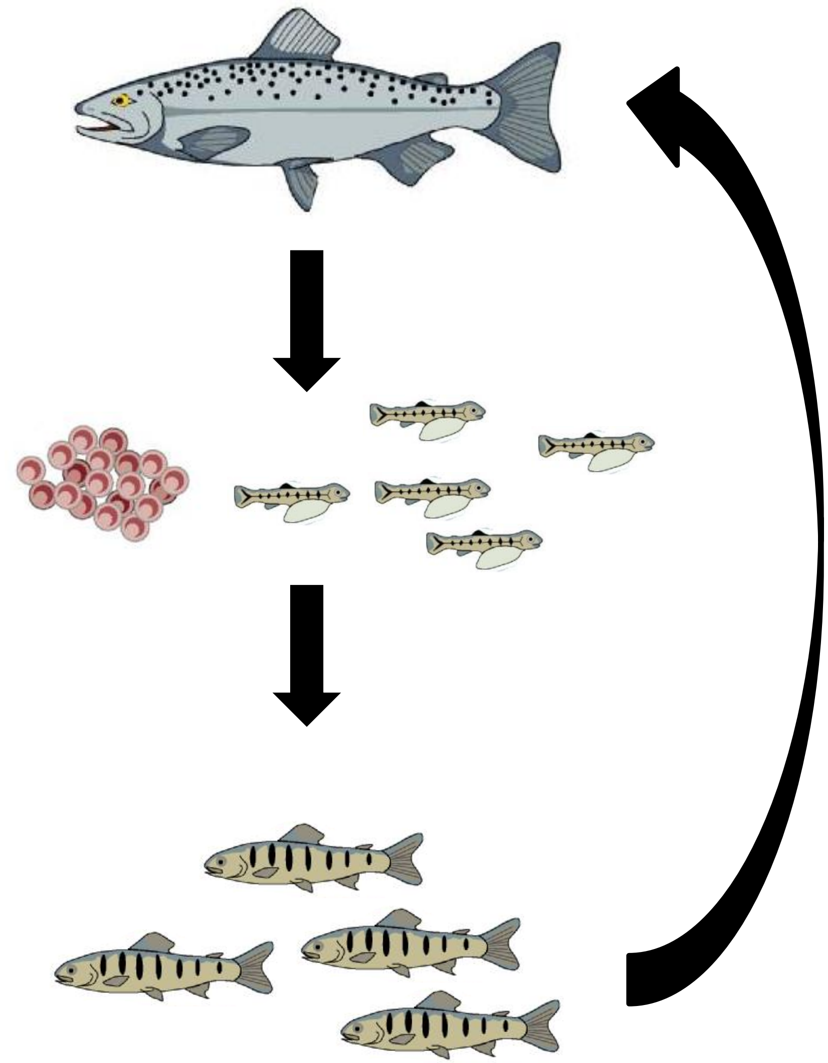


Spawning Success – Substrate Suitability

D50 = Median grain size (mm)

- Reach-scale model (200-m)
- John Day-specific parameterization
  - Bank-full depth (α, β)
  - Channel classifications (n, k)

- Classified reaches for steelhead

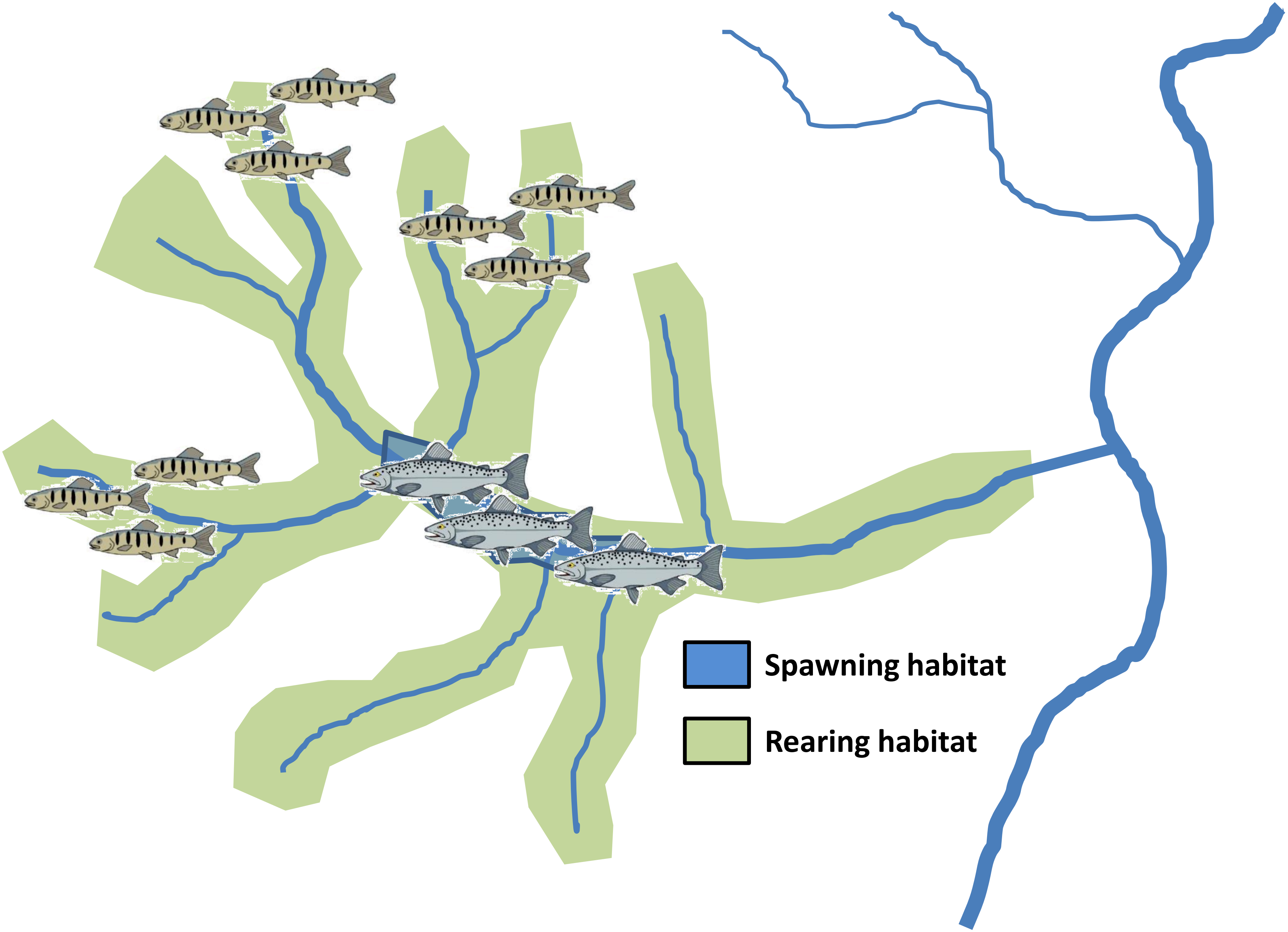
Buffington et al. 2004:

$$D50 = \frac{(\rho \alpha A^{\beta} S)^{1-n}}{(\rho_s - \rho) k g^{n}}$$

Kondolf & Wolman 1993:

Steelhead D50: P_{25} :10-18 mm
P_{50} :18-34 mm
P_{75} :34-48 mm

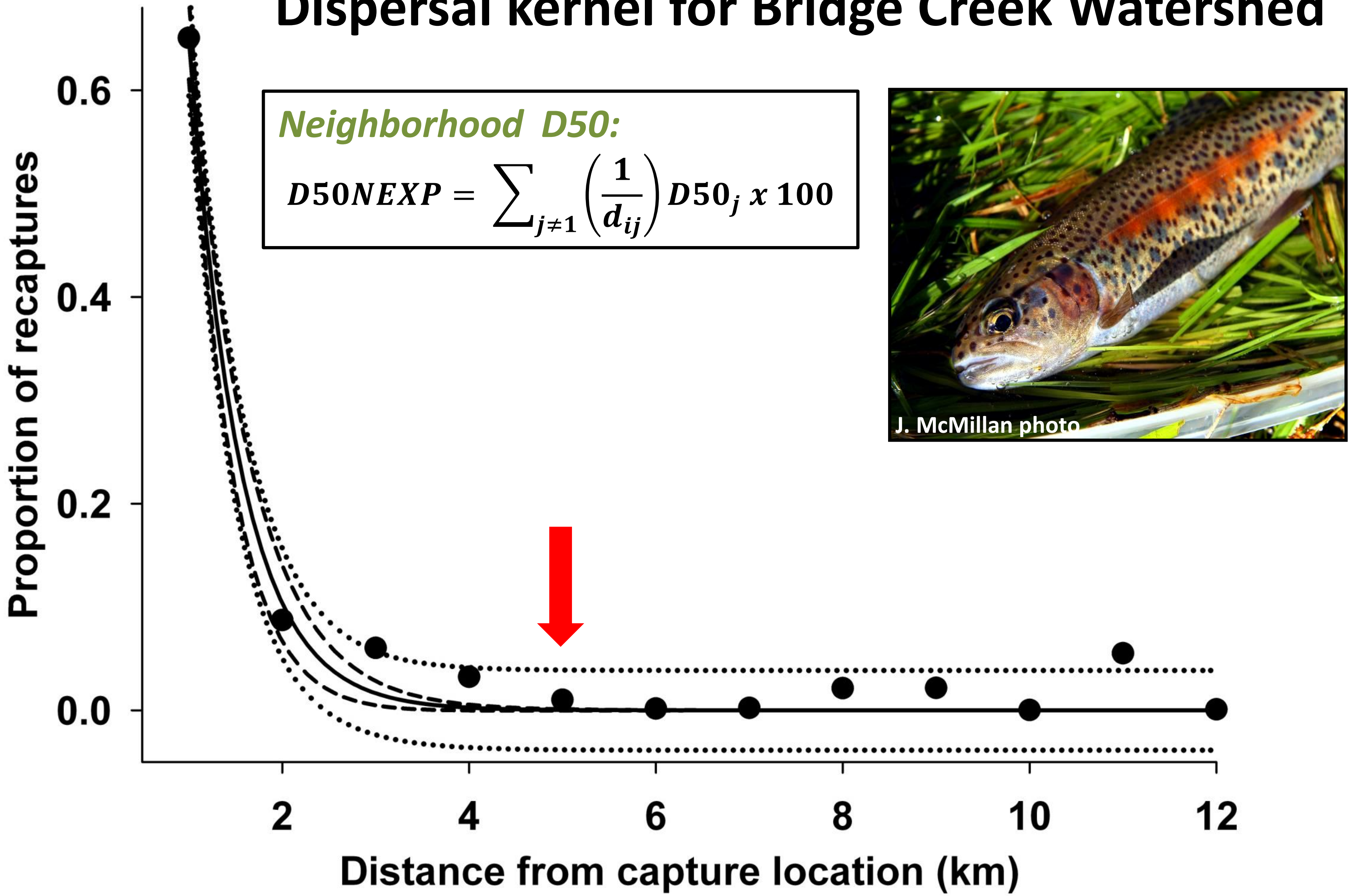
What is a neighborhood for juvenile steelhead?



Dispersal kernel for Bridge Creek Watershed

Neighborhood D50:

$$D50NEXP = \sum_{j\neq 1}\left(\frac{1}{d_{ij}}\right) D50_j \; x \; 100$$



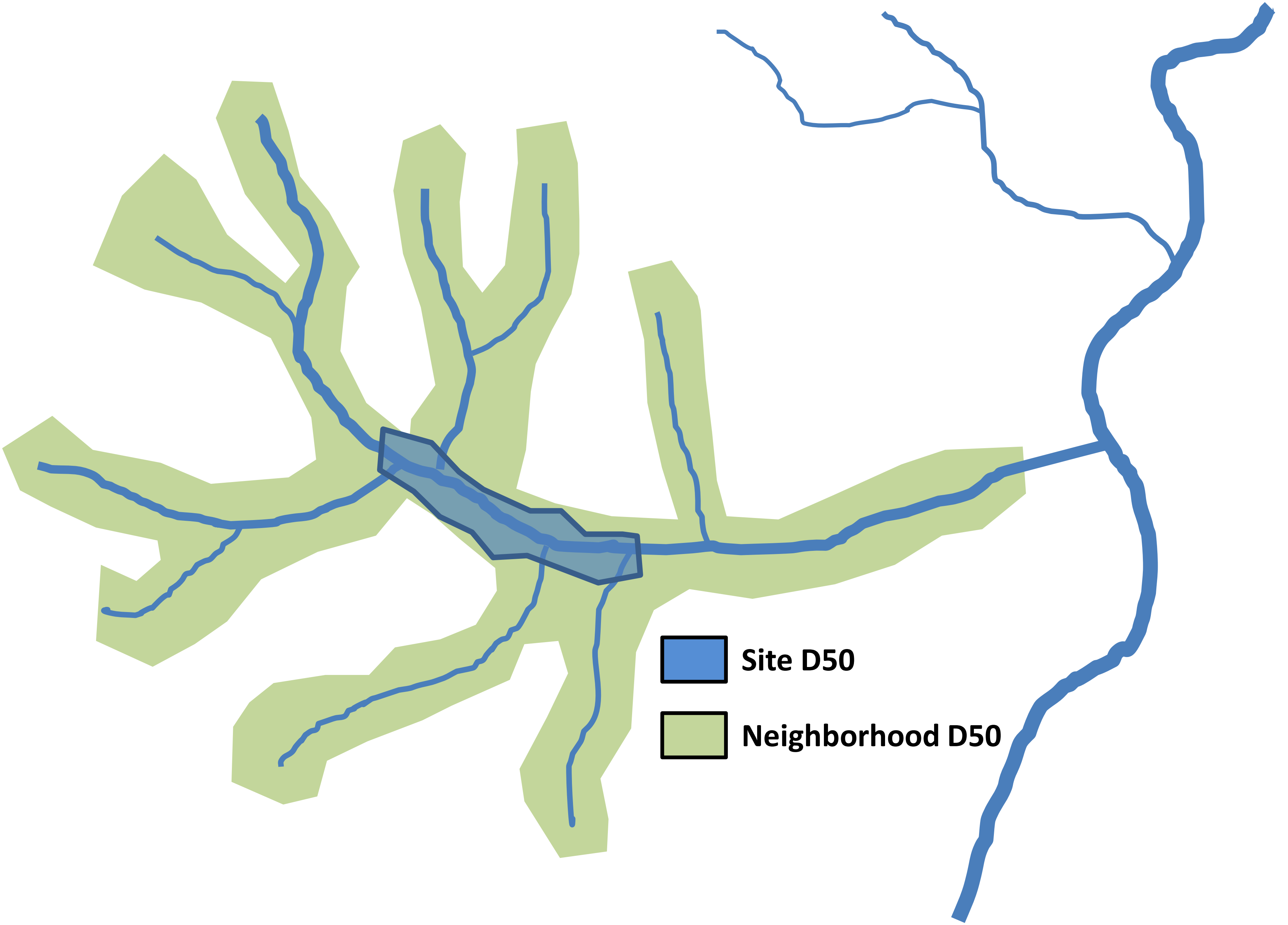
$N = ae^{(-bx)}$ $R^2 = 0.98$ $P < 0.001$

a = 4.07 ± 0.7 SE

----- 95% Confidence Band

.... 95% Prediction Band

Spawning Success – Substrate Suitability



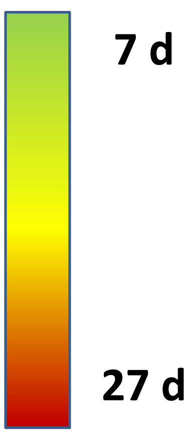
Spawning Success – High Flow Events (Scour)

- **Scour likelihood**
  (Montgomery et al. 1996; Fausch et al. 2001)

- **# days in Spring among highest 5% flow**

- **Spring = Feb 1 – June 30**

Frequency of high spring flows (S95)



Steelhead Freshwater Life-Cycle: Key Processes

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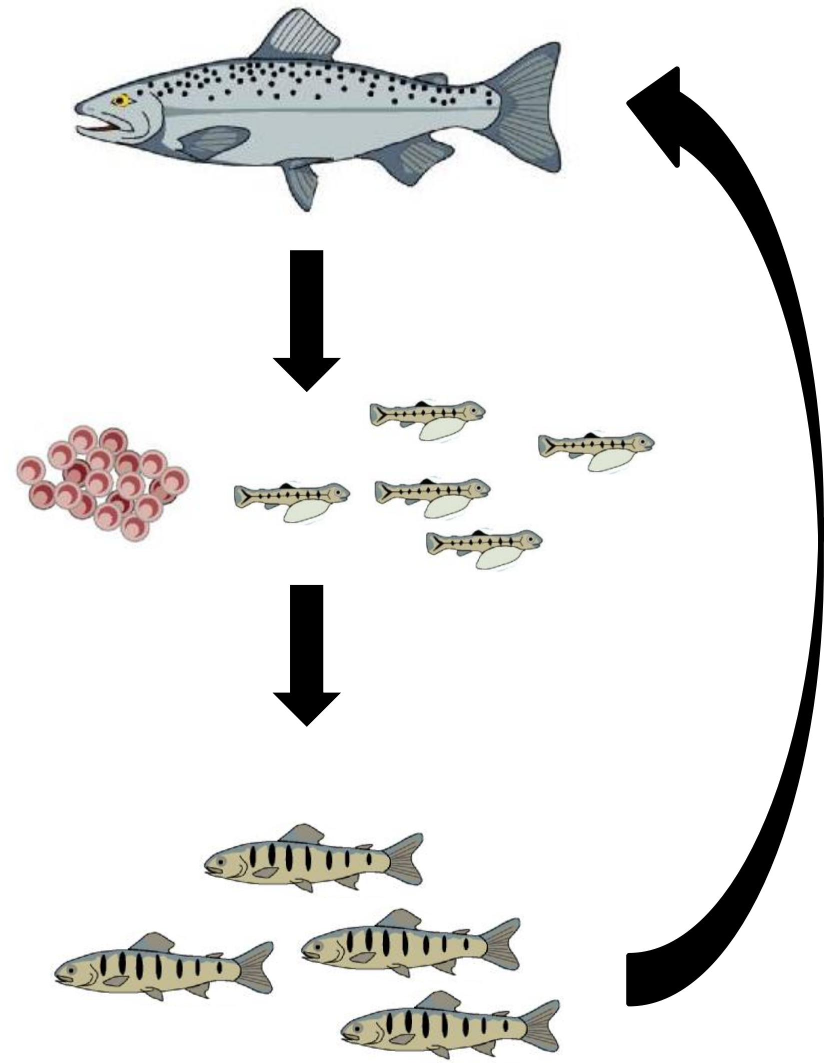
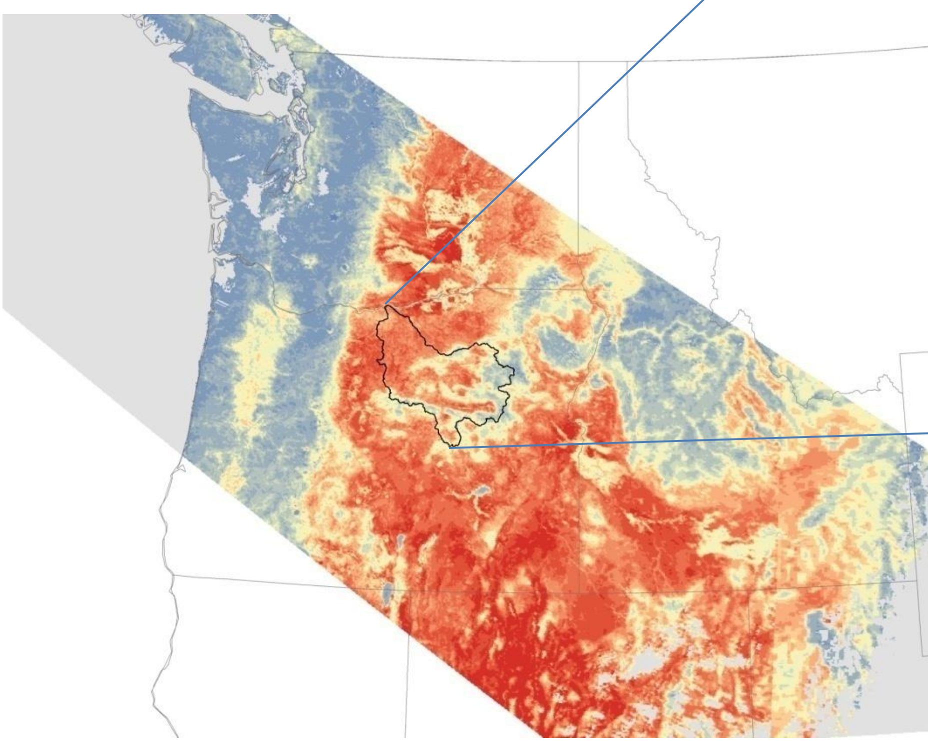


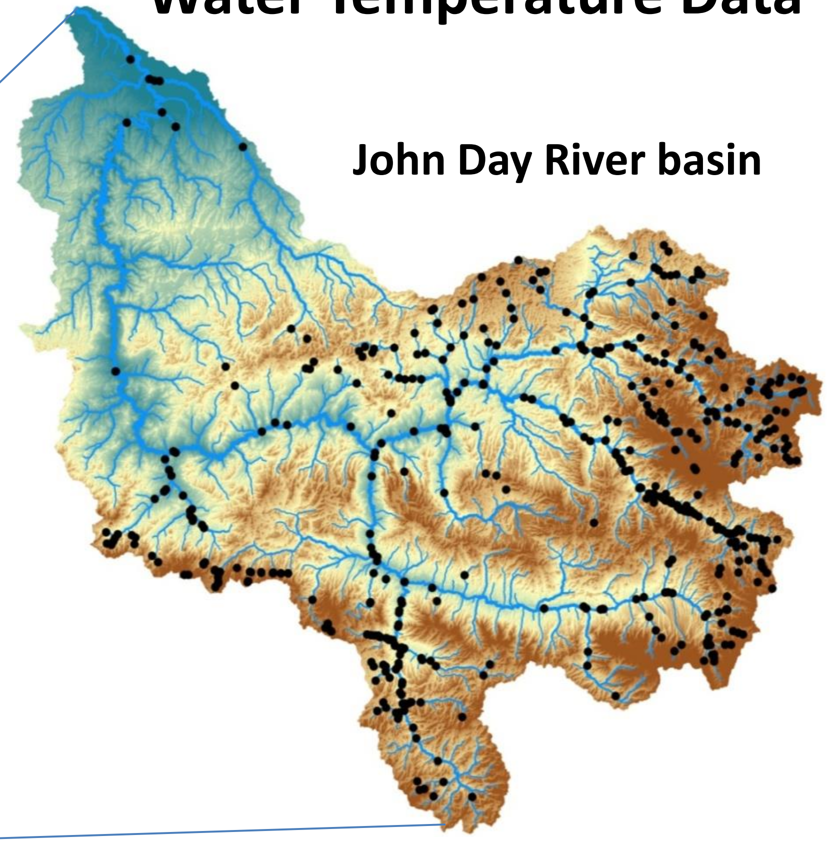
Thermal regime

- MODIS Satellite Data (NASA)
- 1km^2 spatial resolution, daily
- Spatially and temporally “continuous”



Land Surface Temperature (LST)

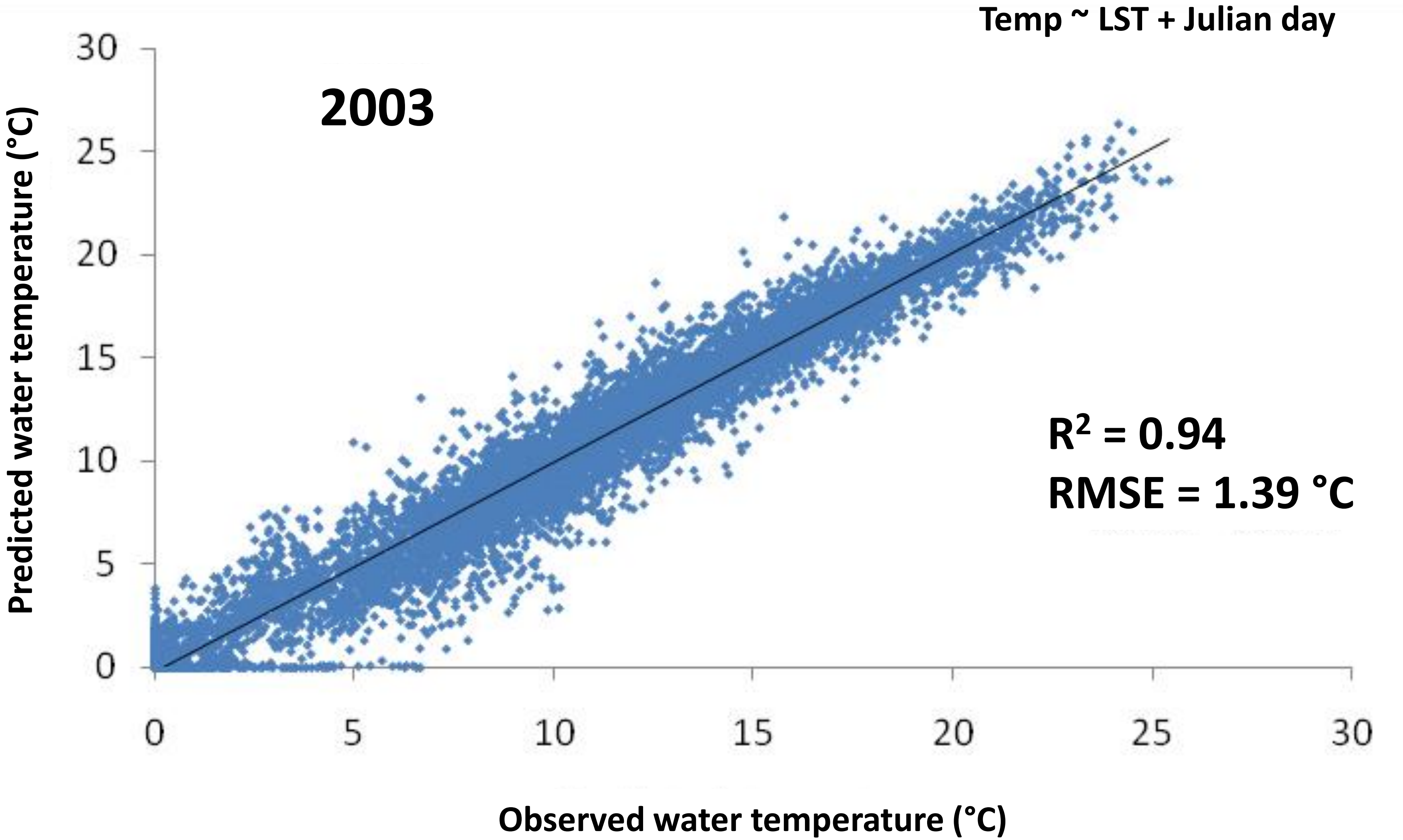
Water Temperature Data



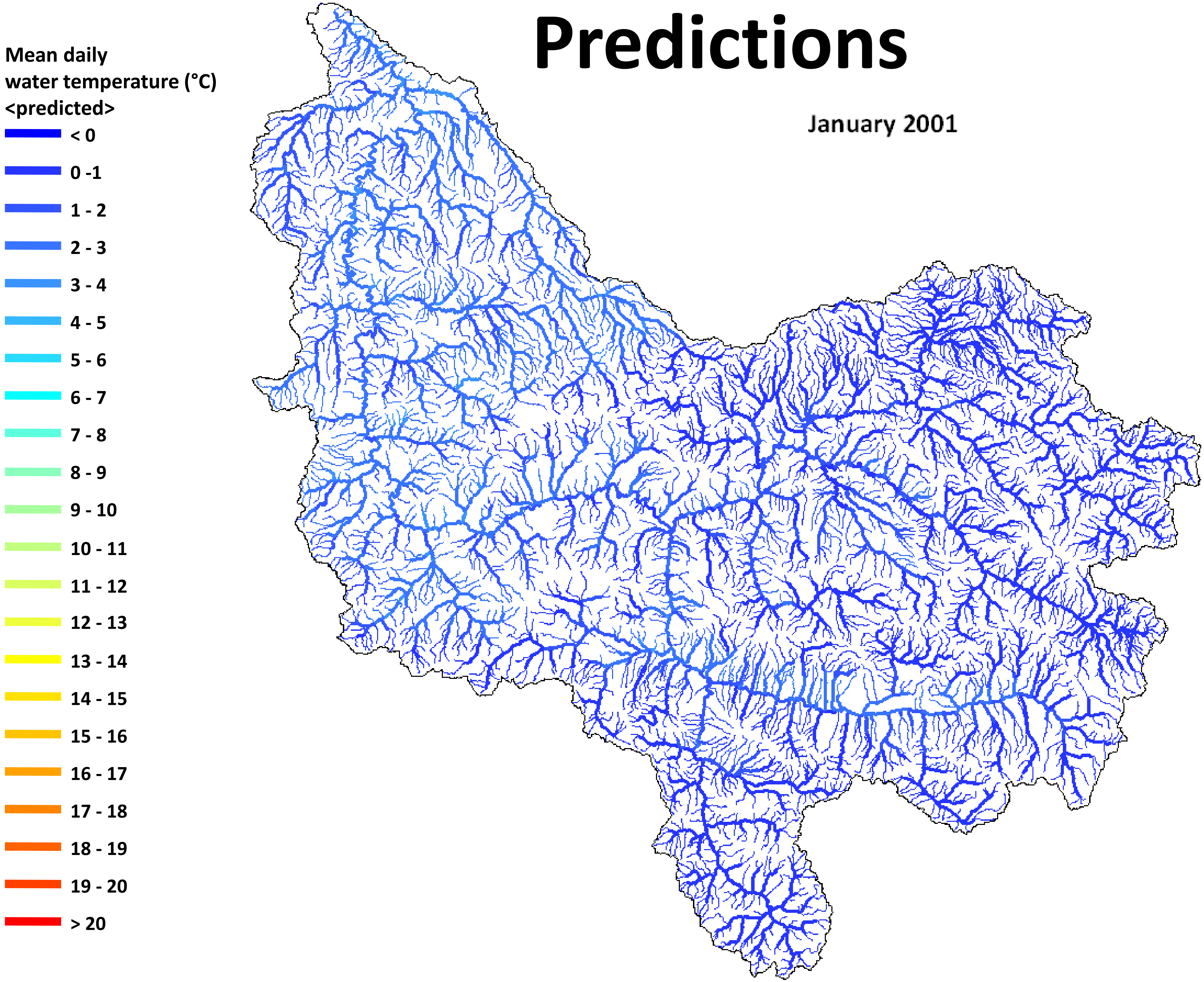
- Stream temp logger dataset
- ~1757 loggers
- Spatially and temporally patchy

(McNyset et al. *in prep*)

Modeling thermal regimes

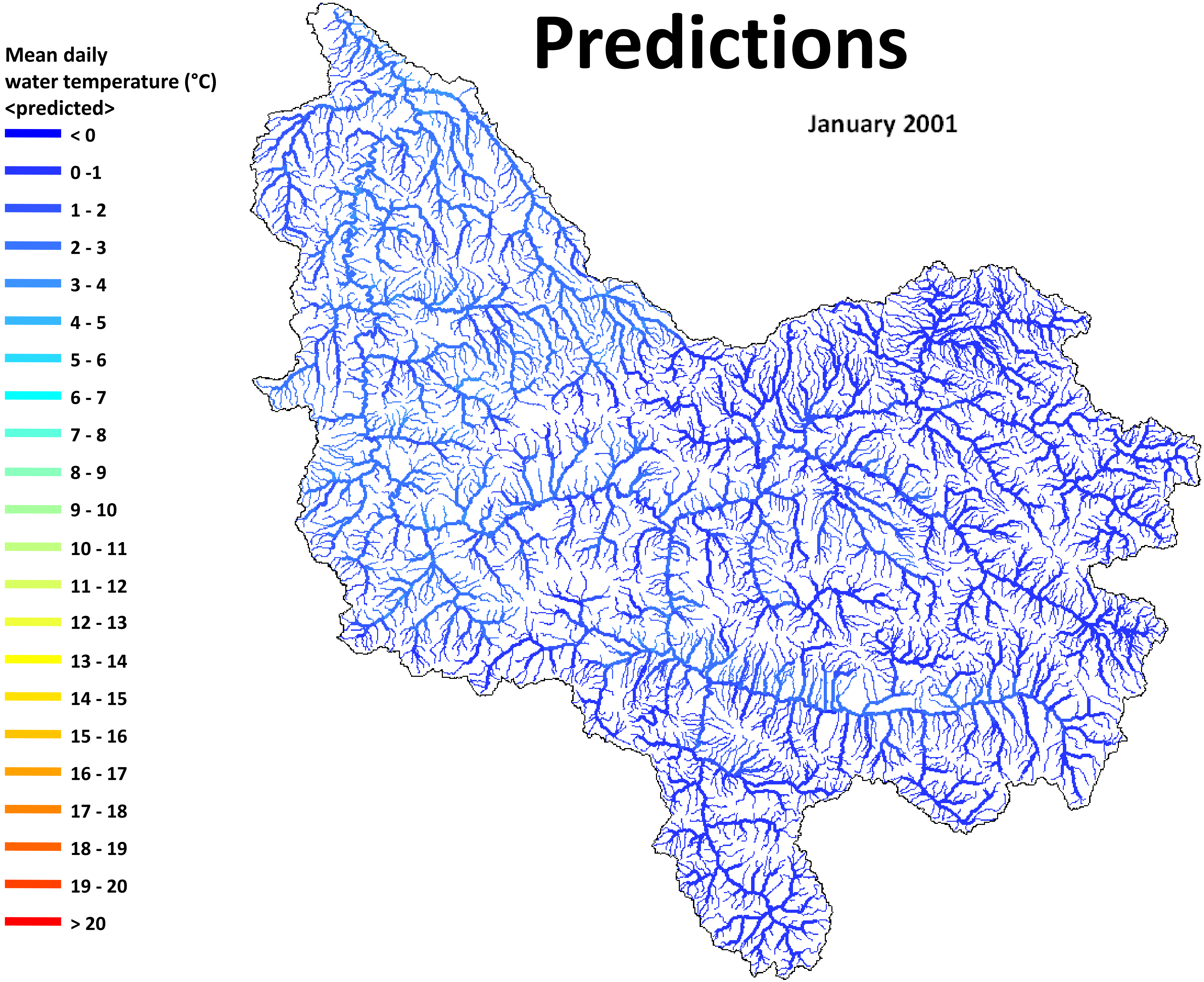


(McNyset et al. *in prep*)

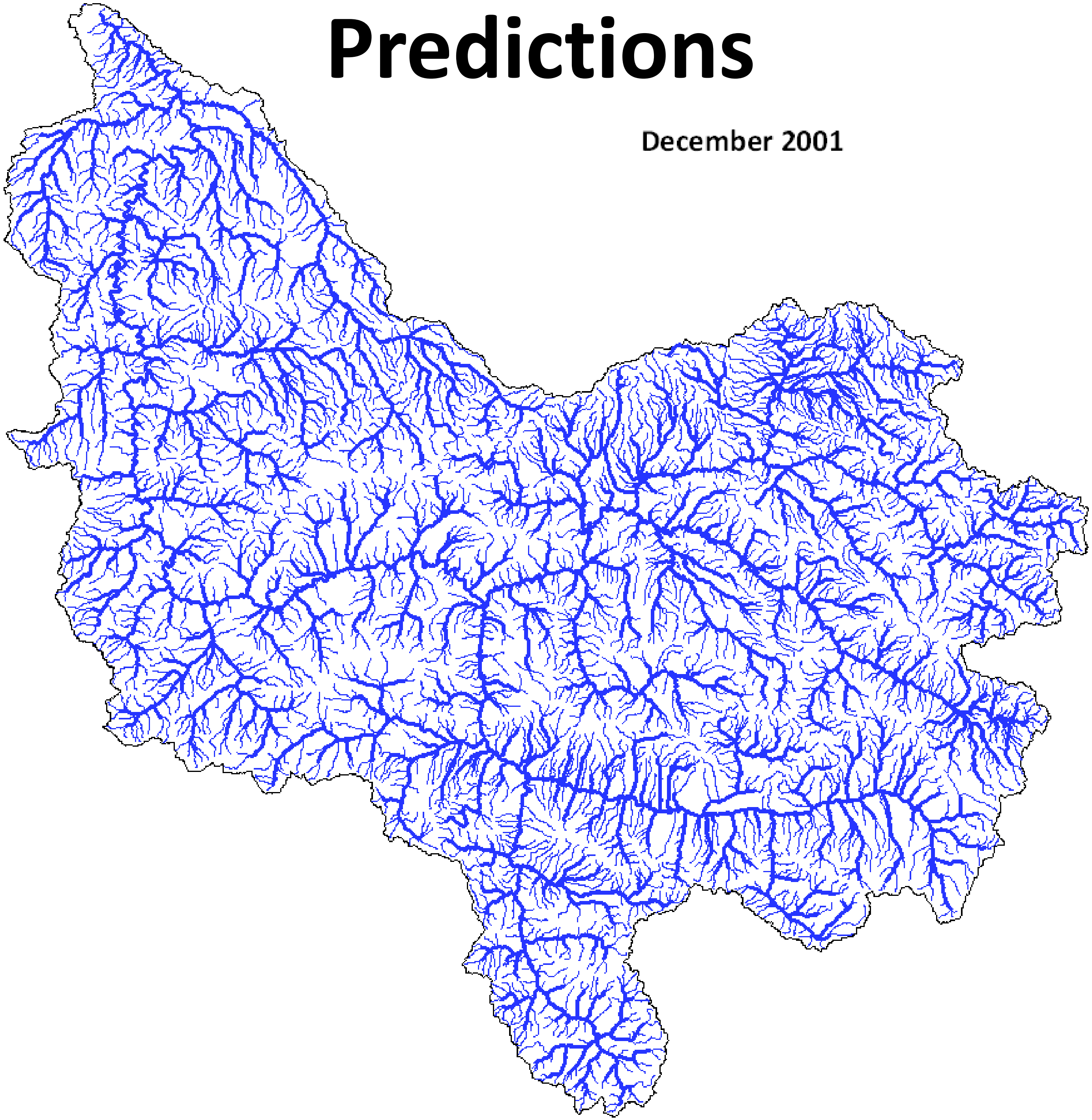


Predictions
January 2001
Mean daily
water temperature (°C)
<predicted>
< 0
0 -1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
9 - 10
10 - 11
11 - 12
12 - 13
13 - 14
14 - 15
15 - 16
16 - 17
17 - 18
18 - 19
19 - 20
> 20

Predictions



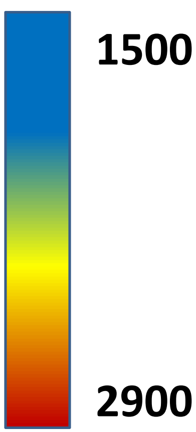
Predictions

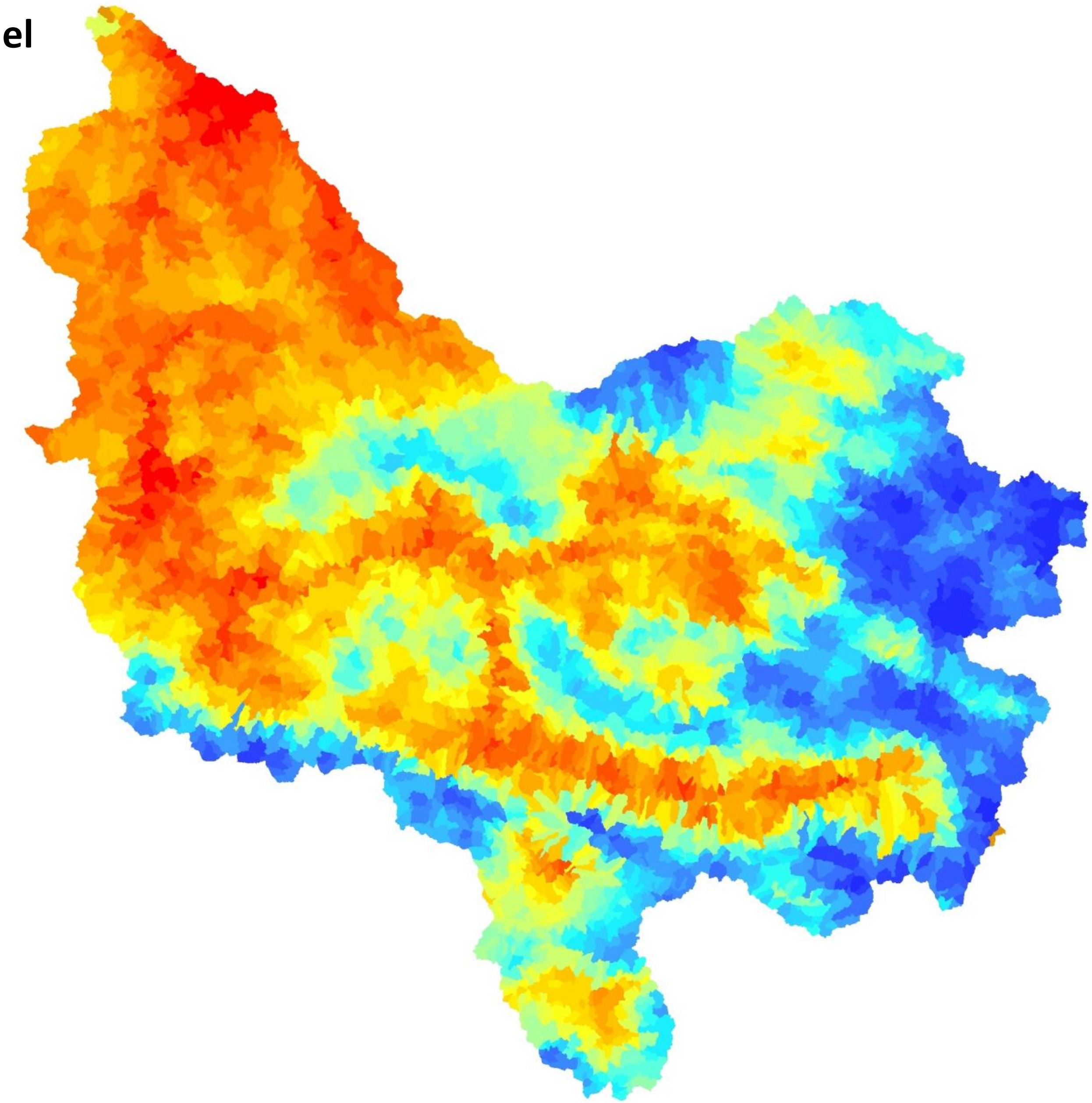


Juvenile habitat-thermal regime

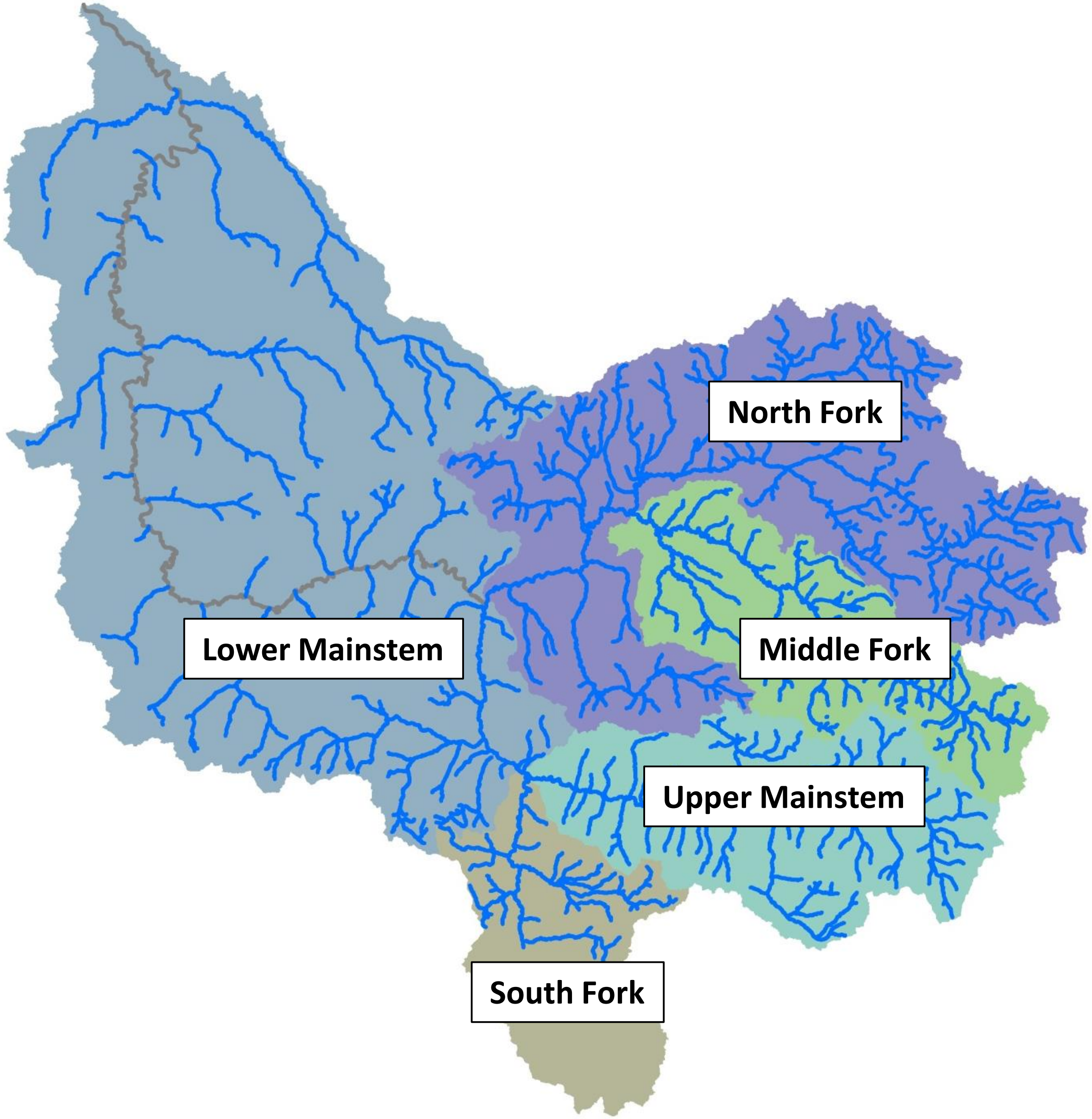
- **Riverscape temperature model (McNyset et al. *in prep*)**
- **Cumulative growing season degree-days (°C)**
- **May 1 – Oct 31**
- **Averaged across 10 years**

Growing season degree days (GSDD)





Spatial Structure / Hatchery Effects?



Candidate Models

Life stage	Covariate	P/A	Count
Maternal survival and access	Stream size	X	
	Distance x Elevation	X	
Spawning success	Site D50	X	
	Neighborhood D50	X	
	Scour likelihood		X
Juvenile growth/survival	Thermal regime	X	X
Population	TRT (Categorical)		X

Site-level predictors (2-km reaches) — blue

Neighborhood-level predictors (5+ km surrounding sites) — green

Hurdle regression model (Colin & Trivedi 1998; 2005; Zuur et al. 2009):

$$f_{hurdle}(y;\beta,\gamma) = \begin{cases} f_{binomial}(y=0;\gamma) & y=0 \\ 1 - f_{binomial}(y=0;\gamma)\ x\ \dfrac{f_{negbin}(y;\beta)}{1-f_{negbin}(y=0;\beta)} & y>0 \end{cases}$$

Model selection results

Model	AIC_c	K	ΔAIC_c	w_i
Neighborhood only	1091.5	7	0	0.413
Site only	1091.9	6	0.4	0.347
Neighborhood + Sub-basin	1094.2	11	2.7	0.11
Site + Sub-basin	1095.9	10	4.4	0.047
Mixture	1095.9	10	4.4	0.047

Site-level only model

Neighborhood-level only model

Mixture of local and neighborhood

Falke et al. 2013 *PLoS ONE*

Model-Averaged Parameter Estimates

Redd occurrence =

Stream size	+	2x
Site D50	+	2x
Neighborhood D50	+	2x
Thermal regime (GSDD)	+	6x
Distance x Elevation	-	1x*

Redd abundance =

Scour likelihood	-	1x
Thermal regime (GSDD)	+	7x

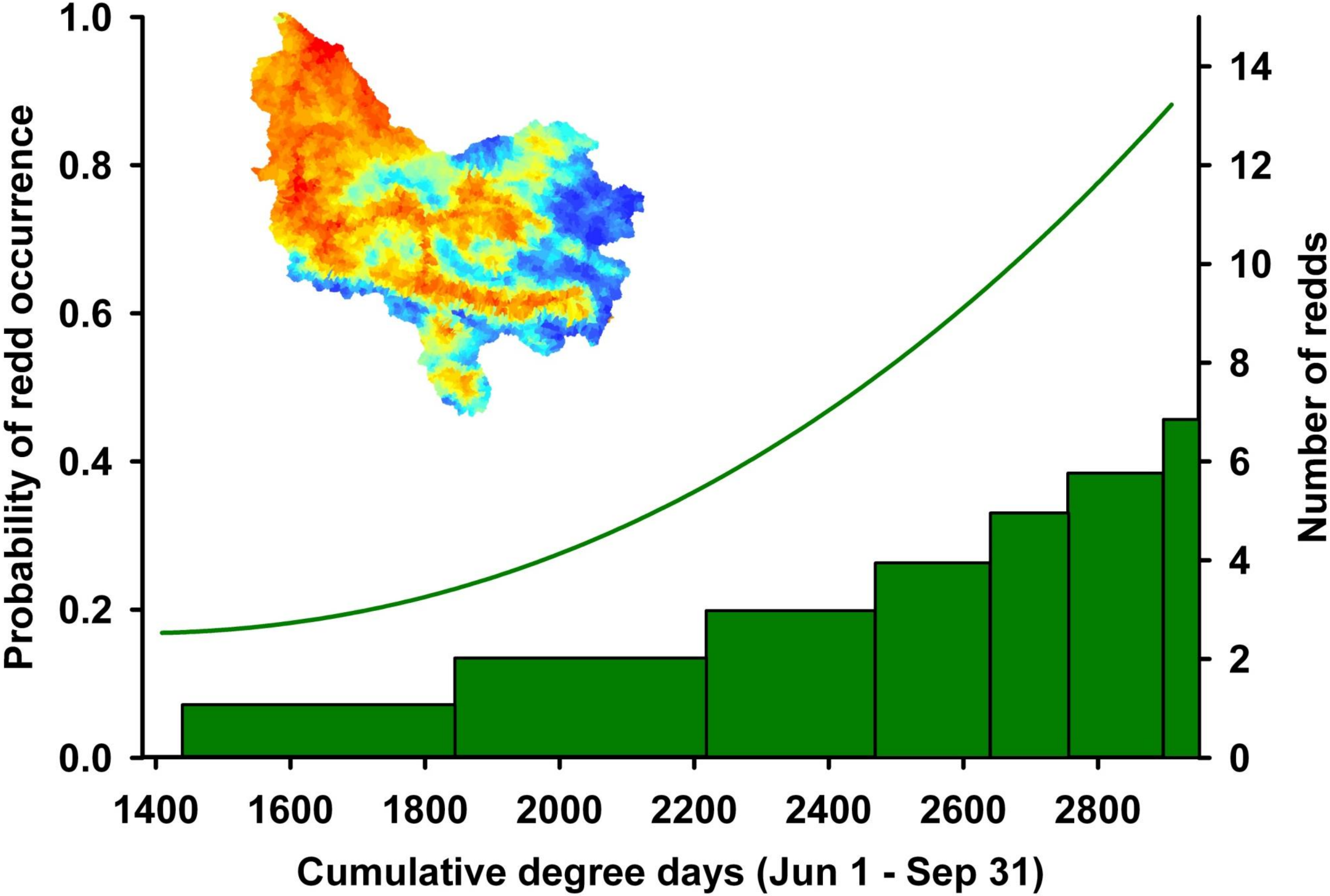
Site-level

Landscape-level

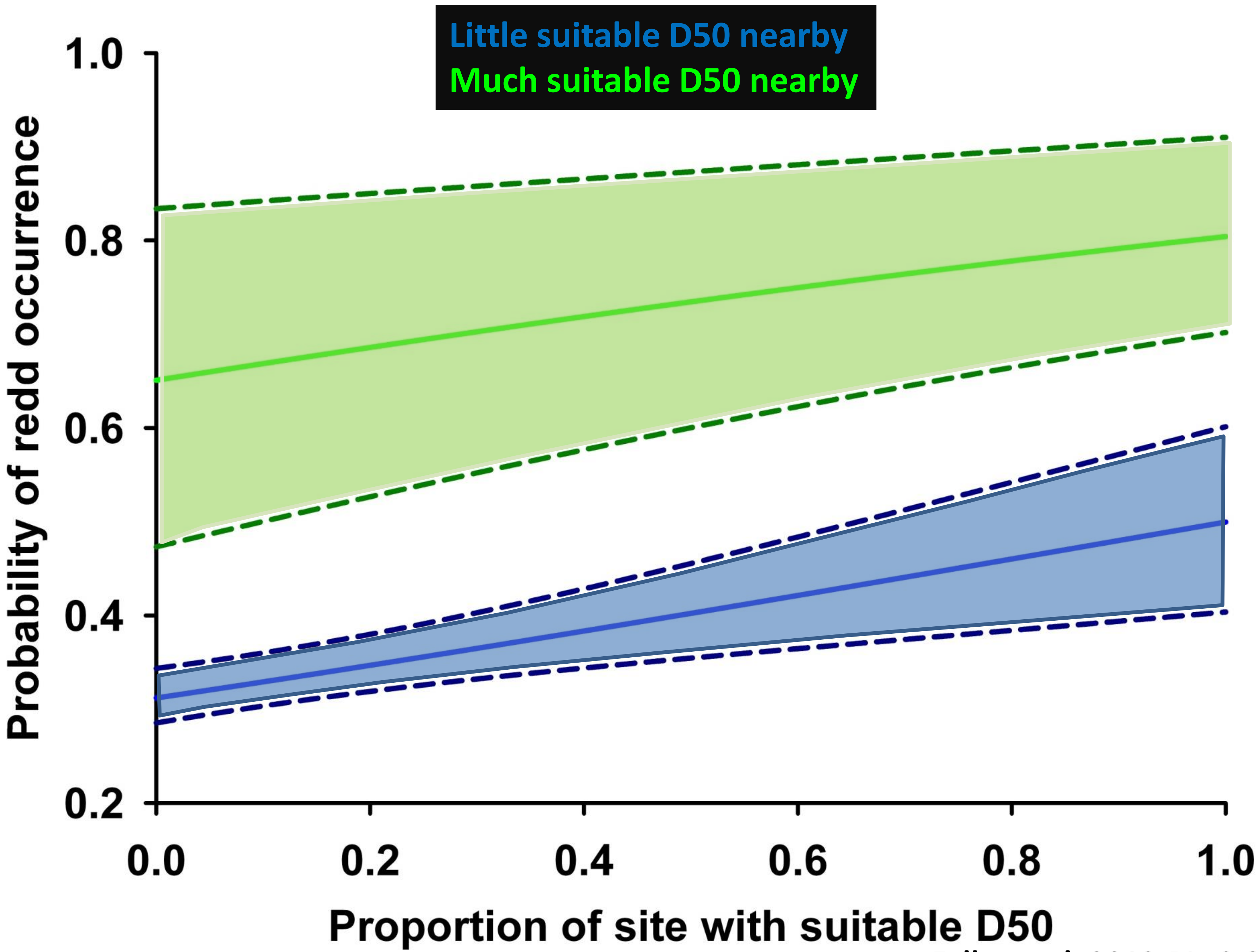
***95% CI overlaps zero**

Falke et al. 2013 *PLoS ONE*

Thermal Regime (GSDD)

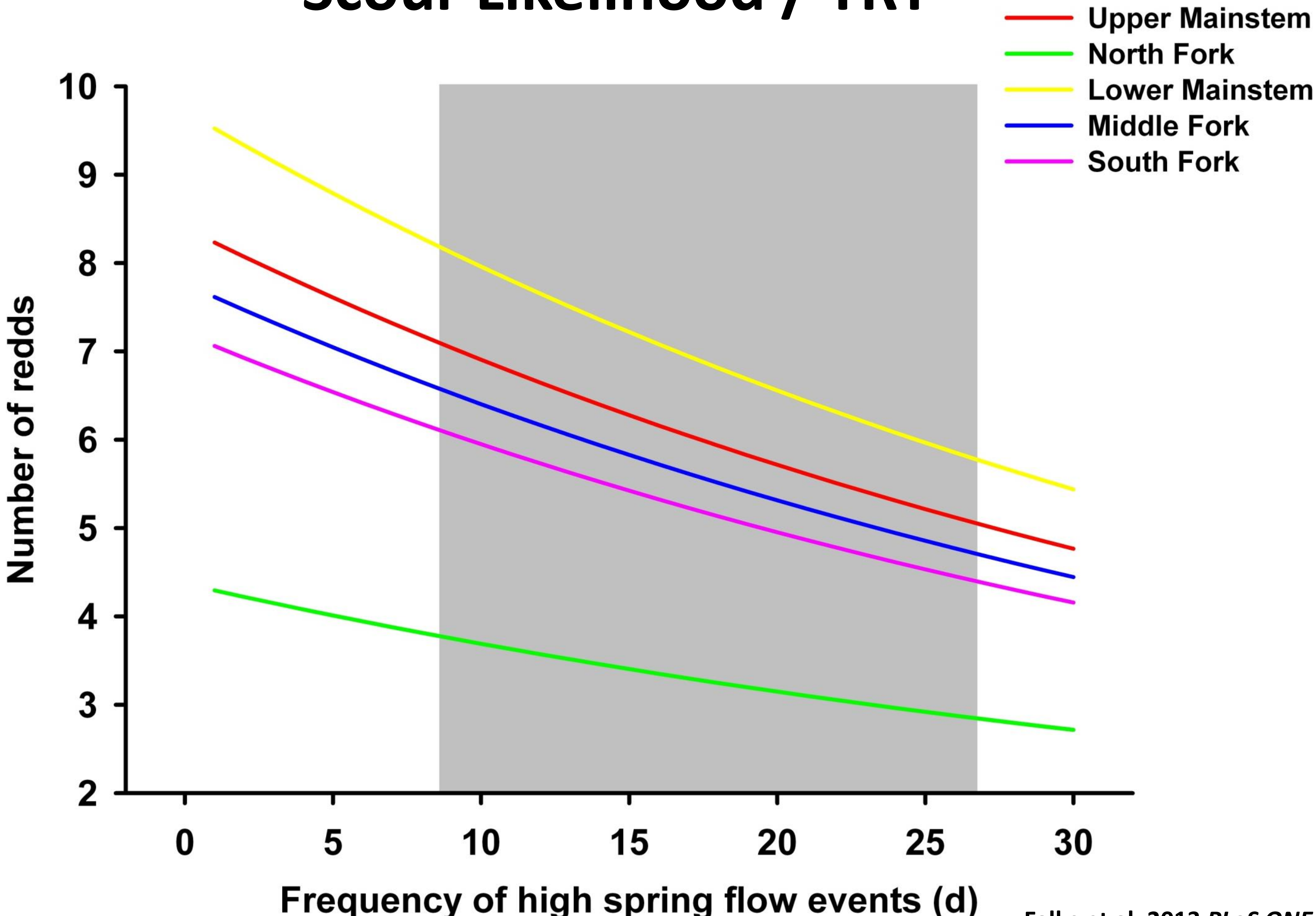


Falke et al. 2013 *PLoS ONE*



Falke et al. 2013 *PLoS ONE*

Scour Likelihood / TRT



Falke et al. 2013 *PLoS ONE*

Among-Model Predictive Diagnostics

	Binomial			Count*			
Model	PCC	AUC		r	ρ	AVE_{error}	RMSE
Composite	0.80	0.90		0.79	0.74	1.17	3.37
Neighborhood only	0.78	0.87		0.82	0.80	0.94	3.93
Site only	0.62	0.81		0.66	0.62	2.44	5.57

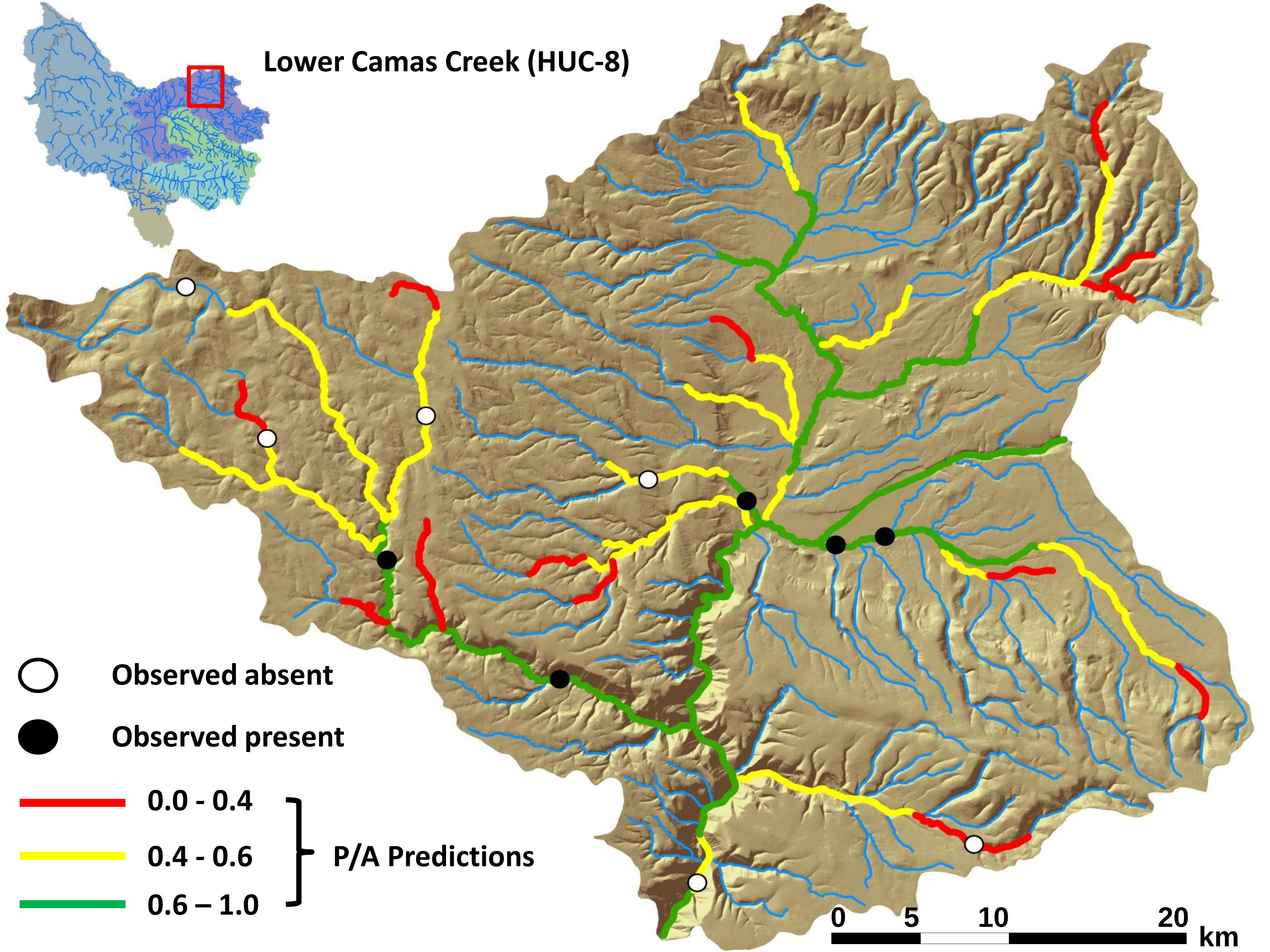
PCC = Proportion correctly classified
AUC = Area under-the-curve statistic
***r* = Pearson's correlation coefficient**
***ρ* = Spearman's rank correlation coefficient**

$$AVE_{error} = \frac{1}{n}\sum_{i=1}^{n}(\hat{y}_i - y_i)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\hat{y}_i - y_i)^2}$$

***Based on "0.632+" bootstrap evaluation (Steyerberg et al. 2001; Potts & Elith 2006)**

Falke et al. 2013 *PLoS ONE*


Lower Camas Creek (HUC-8)
Observed absent
Observed present
0.0 - 0.4
0.4 - 0.6
0.6 – 1.0
P/A Predictions
0
5
10
20
km

Discussion and Implications

General guidelines for modeling spatial process

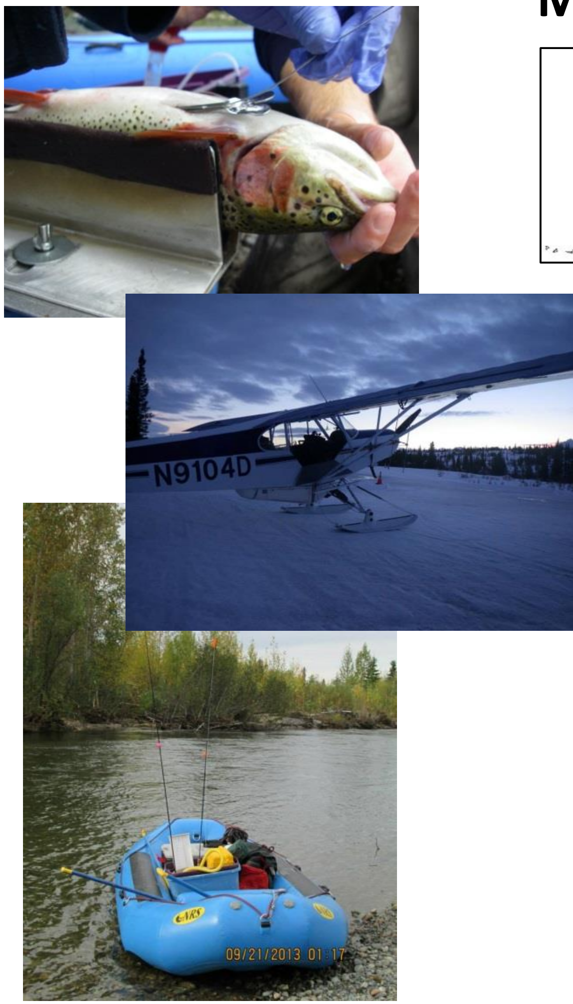
1. *Think like a fish!*

2. *Predictors important across life stages*

3. *Don’t ignore local habitat effects*

4. *Balanced, robust survey design*

Future Directions – Potamodromy



Photos: Kevin Fraley

Matanuska – Susitna River Basin, Alaska

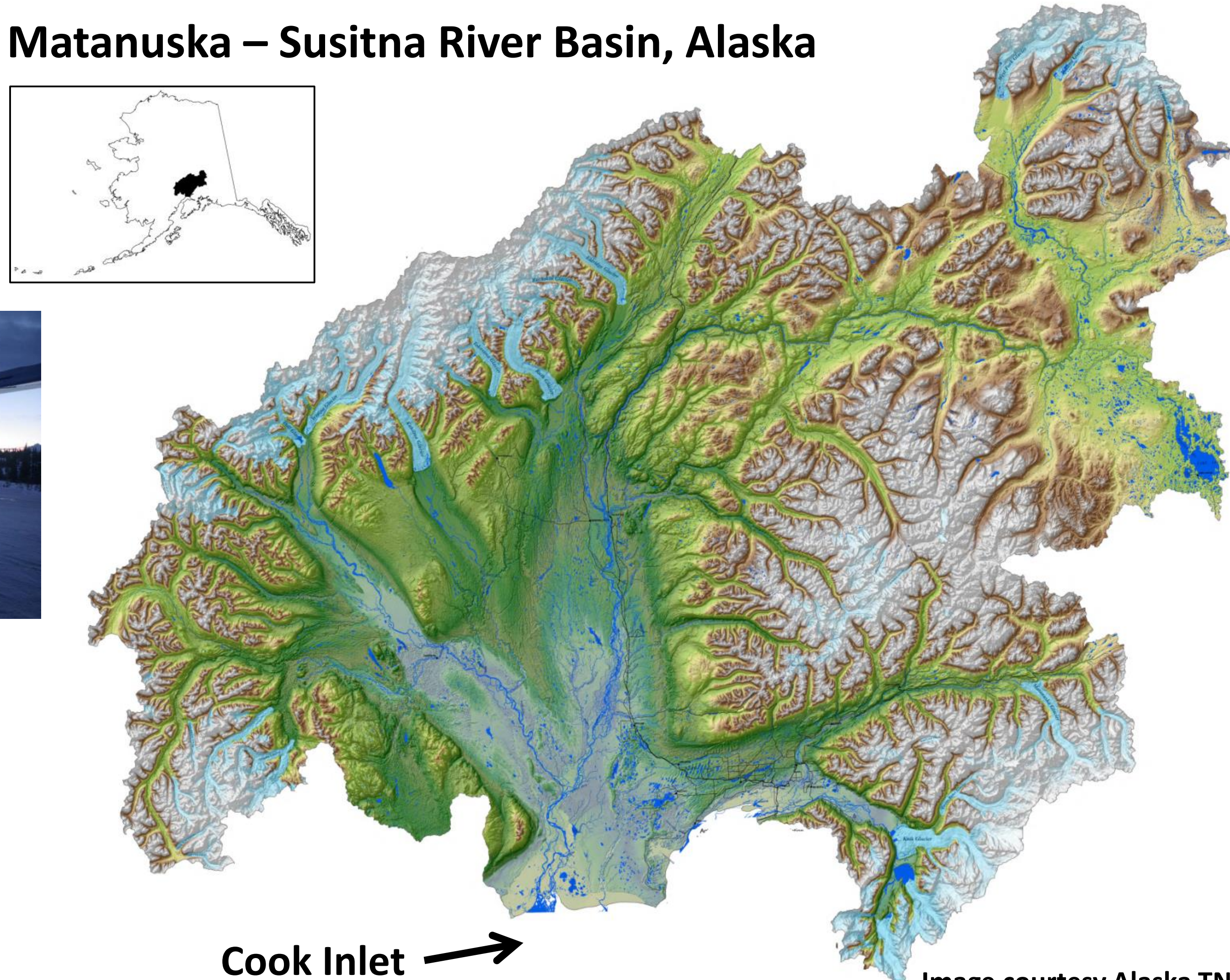


Image courtesy Alaska TNC

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