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science for a changing world

Forecasting environmental change: modeling thermal refugia and brook trout abundance

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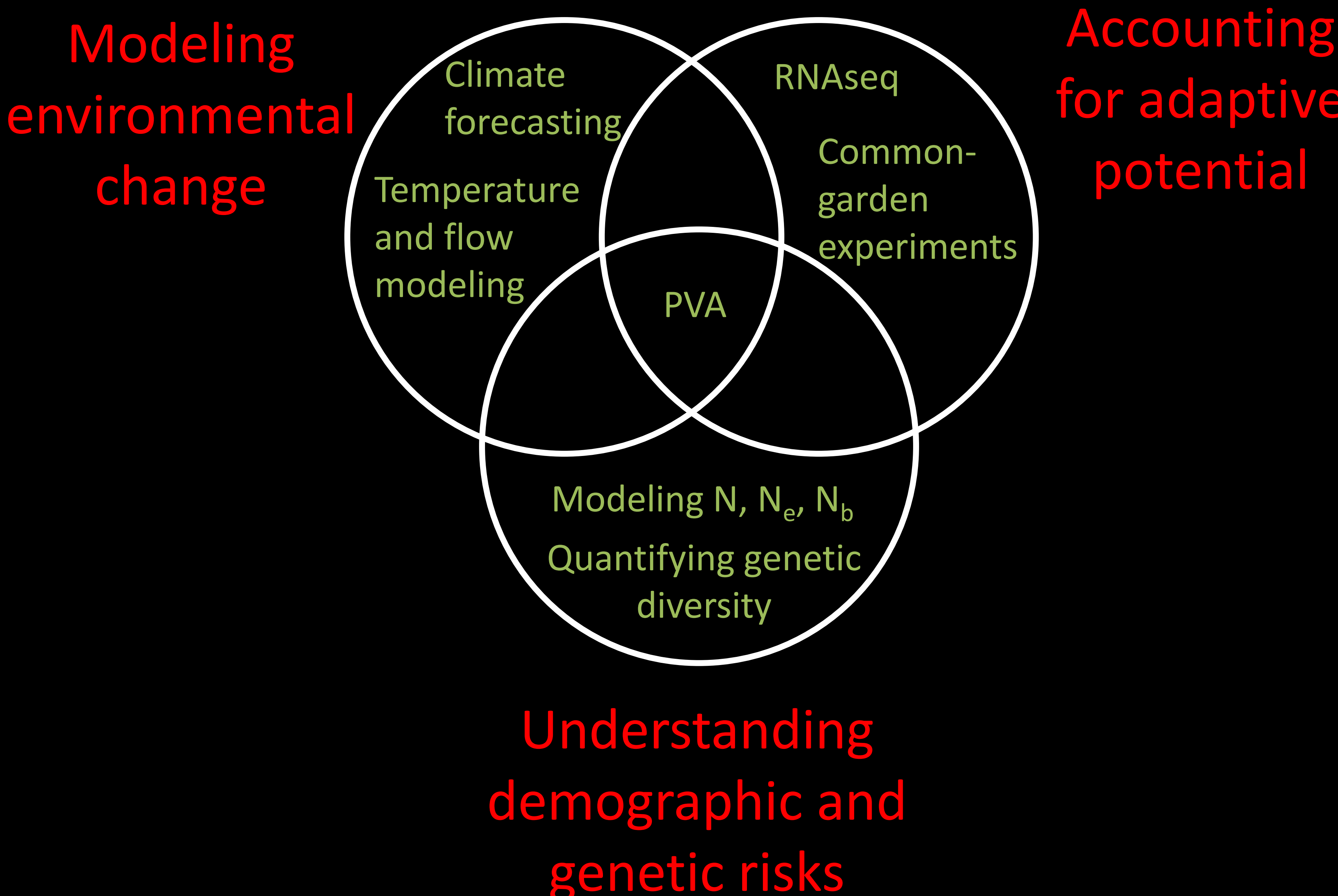
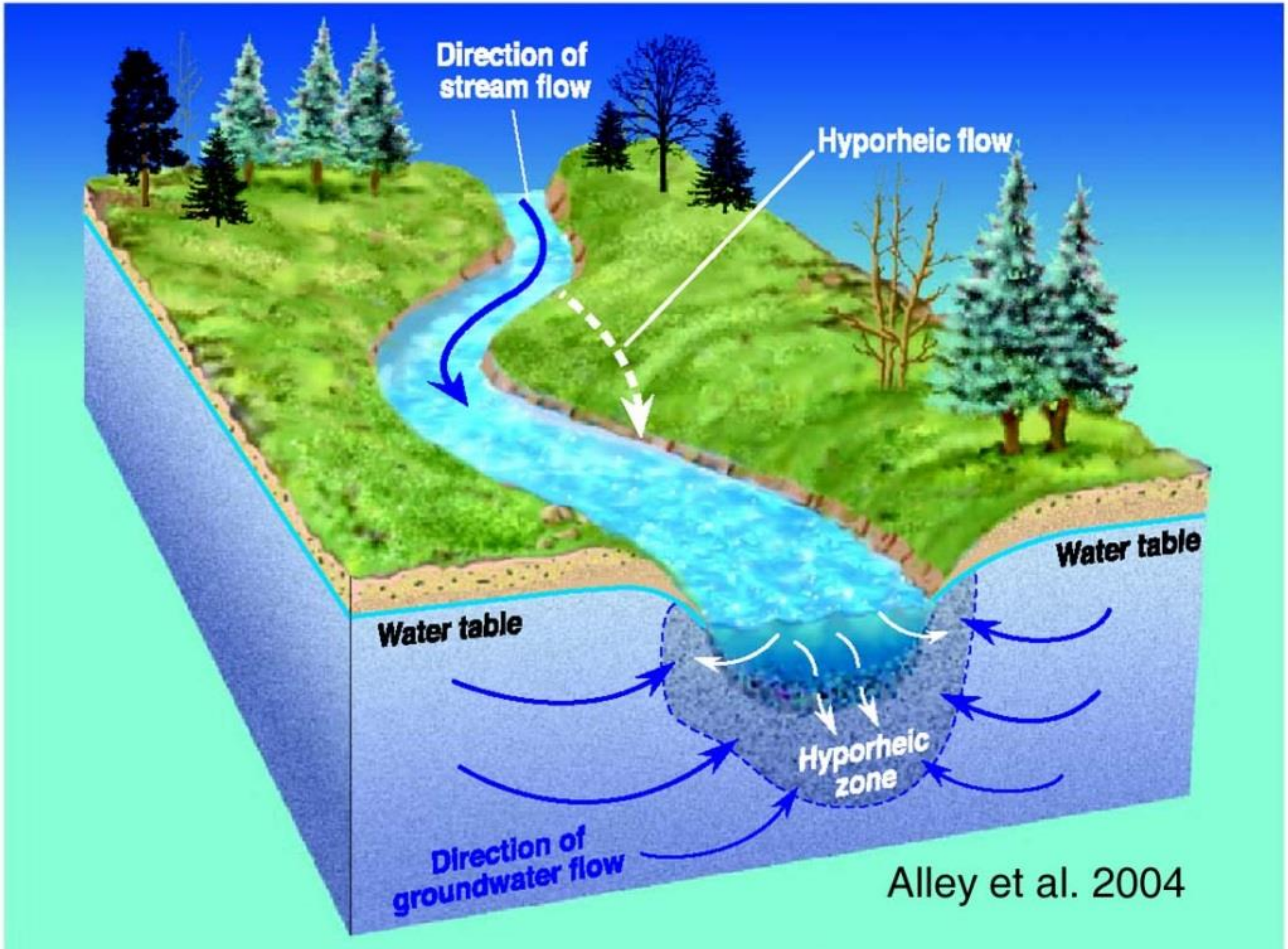


Modeling environmental change
Accounting for adaptive potential
Understanding demographic and genetic risks
Climate forecasting
Temperature and flow modeling
RNAseq
Common-garden experiments
PVA
Modeling N, N_e, N_b
Quantifying genetic diversity

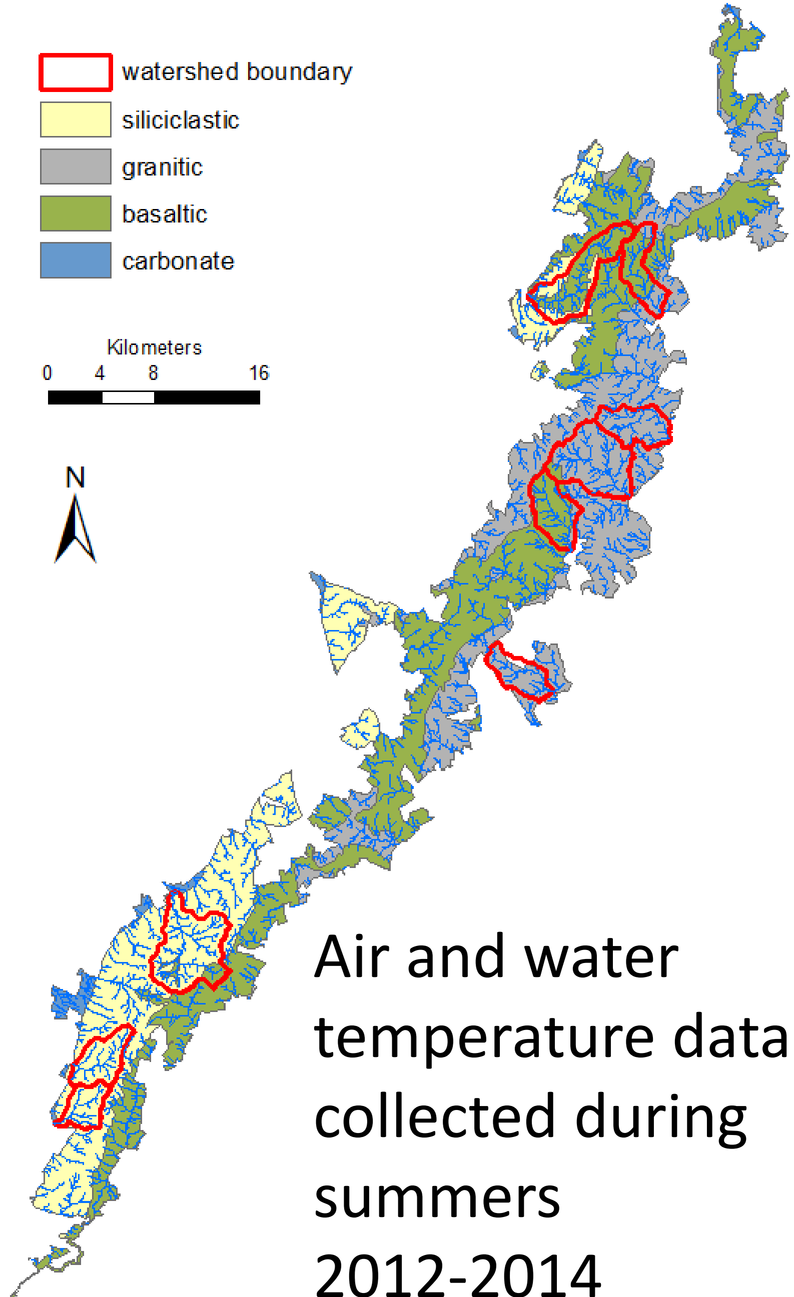
Objective	Input data	Region	Scale	Model	Benefits	Limitations
Modeling groundwater influence on stream temperature	Air/water temperature data	Shenandoah National Park	Stream reach	Multiple linear regression	Computationally simple; uses commonly collected data; provides index of groundwater effect	Requires local stream temperature data
Modeling seasonal climate influence on brook trout abundance	3-pass backpack electrofishing data; 33 years; 3204 samples; Mostly state agency fish data sources; PRISM climate data	PA to GA	Stream reach	Hierarchical Bayesian Models; MCMC	Flexible; Inference from posterior distributions; accounts for detection probability	Processing speed; requires external validation
				Boosted Regression Trees	Internal cross-validation; can model nonlinear responses; partials effects of individual vars	Requires large datasets

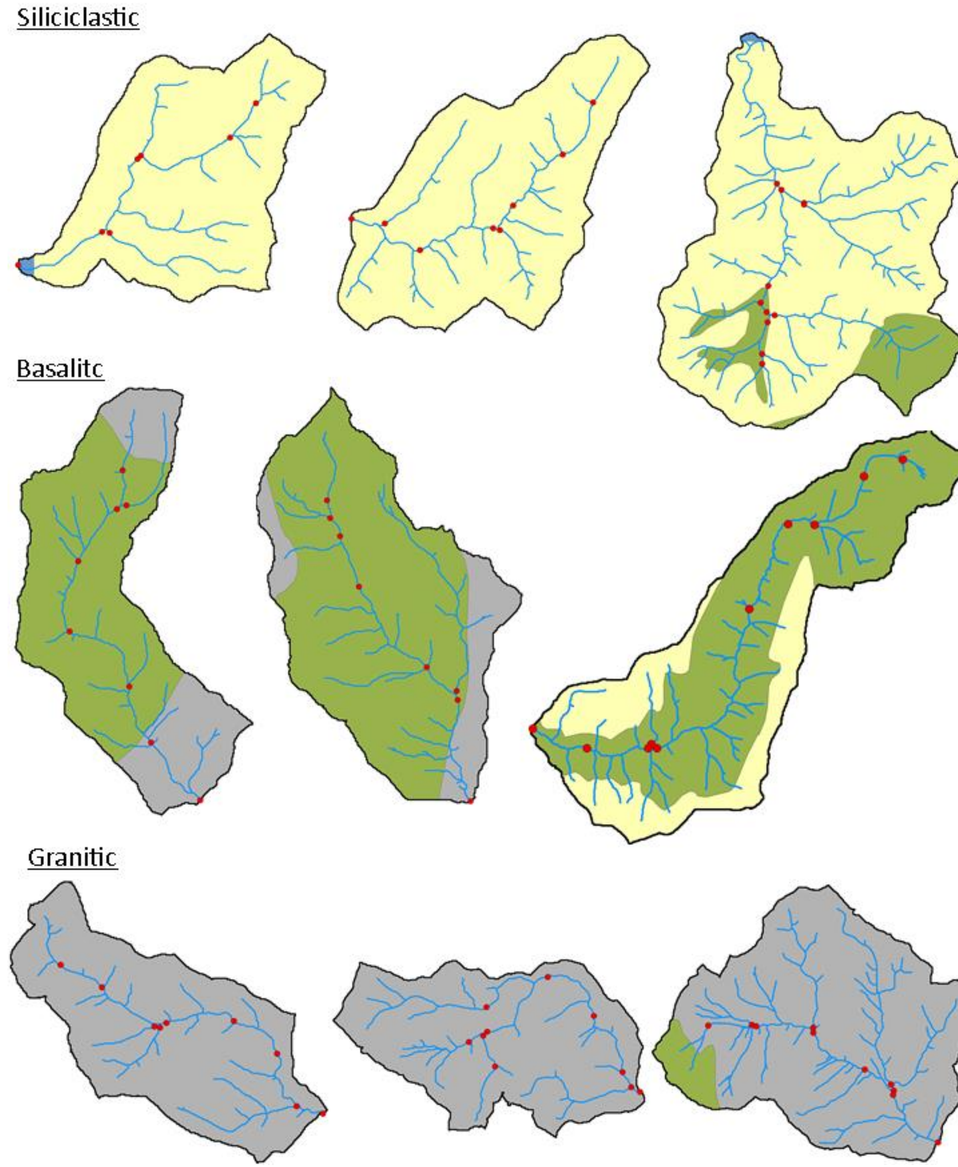
Modeling groundwater influence on stream temperature



Groundwater affects thermal habitat for stream fishes

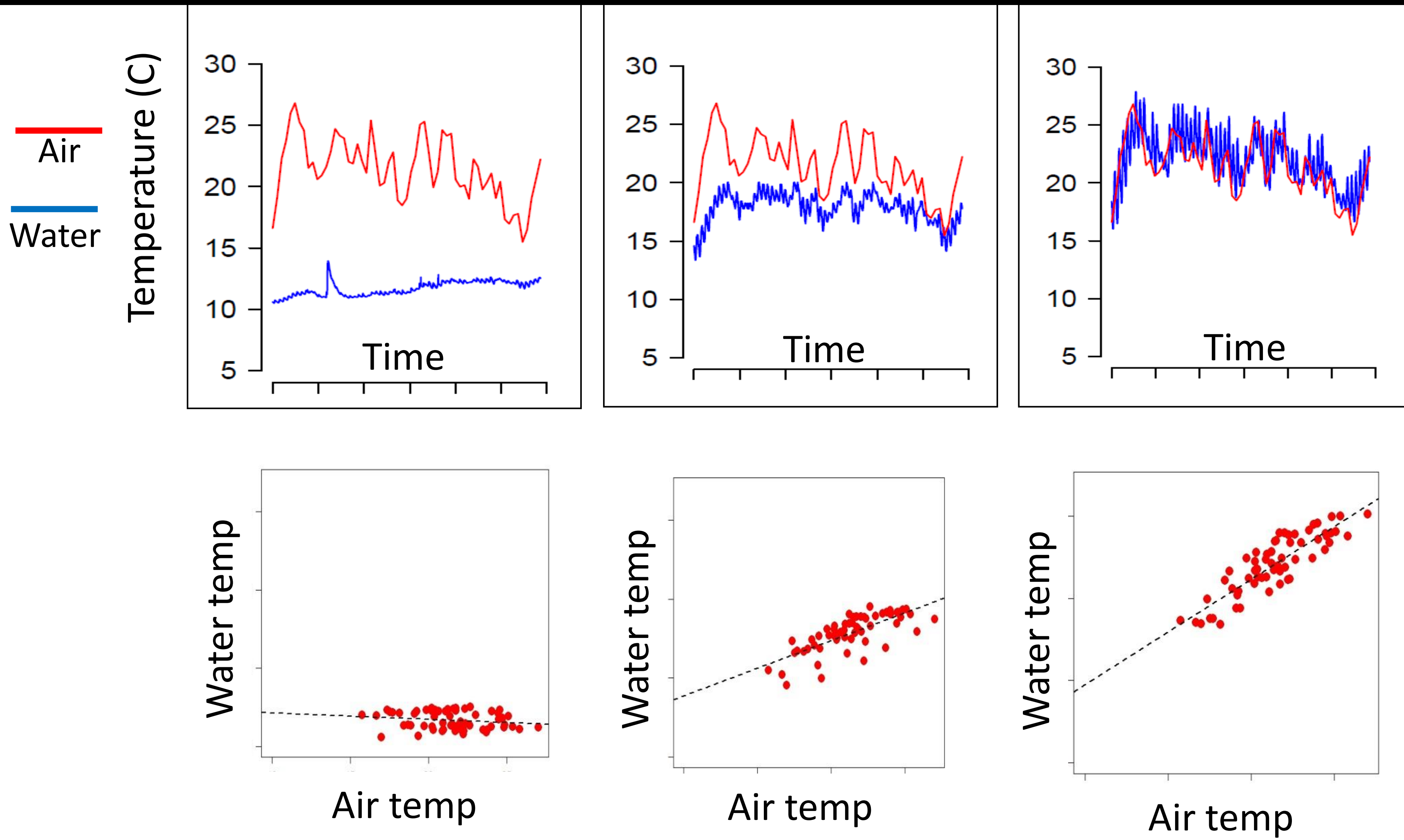
Shenandoah National Park





Air and water temperature data collected during summers 2012-2014

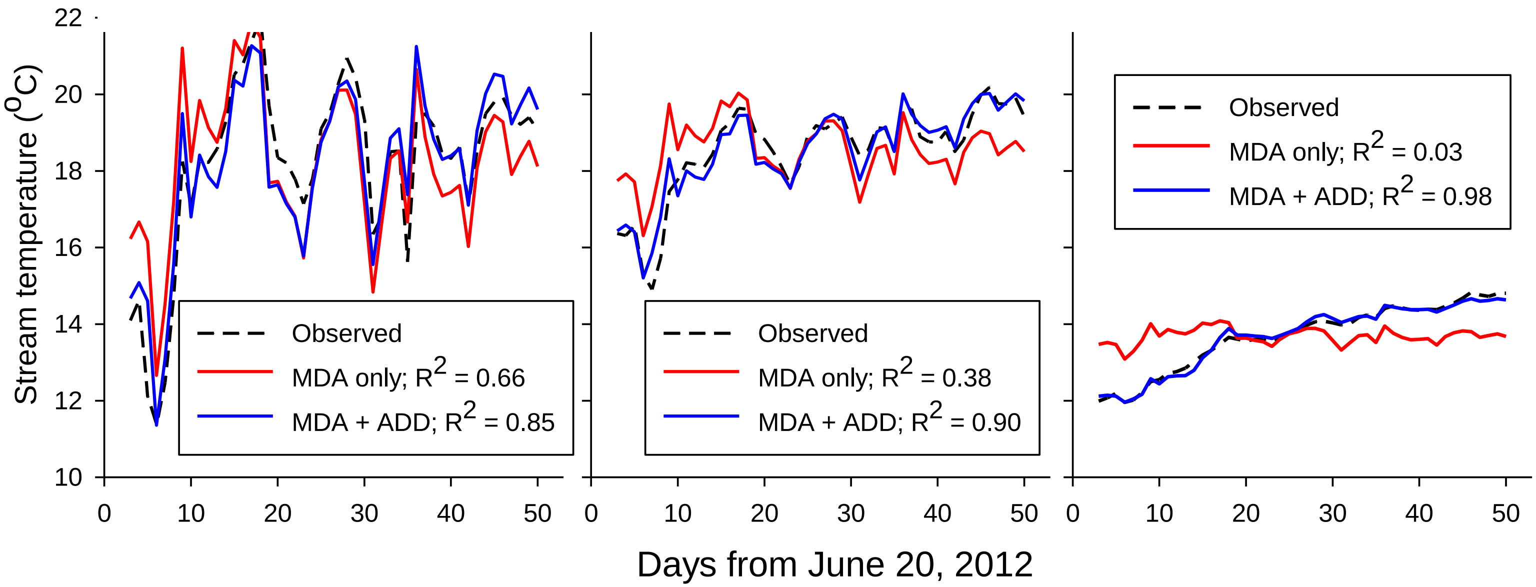
Variation in groundwater influence

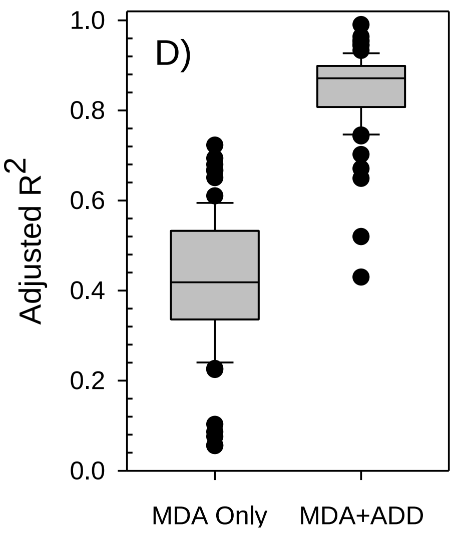


Low sensitivity → *High sensitivity*

Large GW influence → *Small GW influence*

Stream temperature models

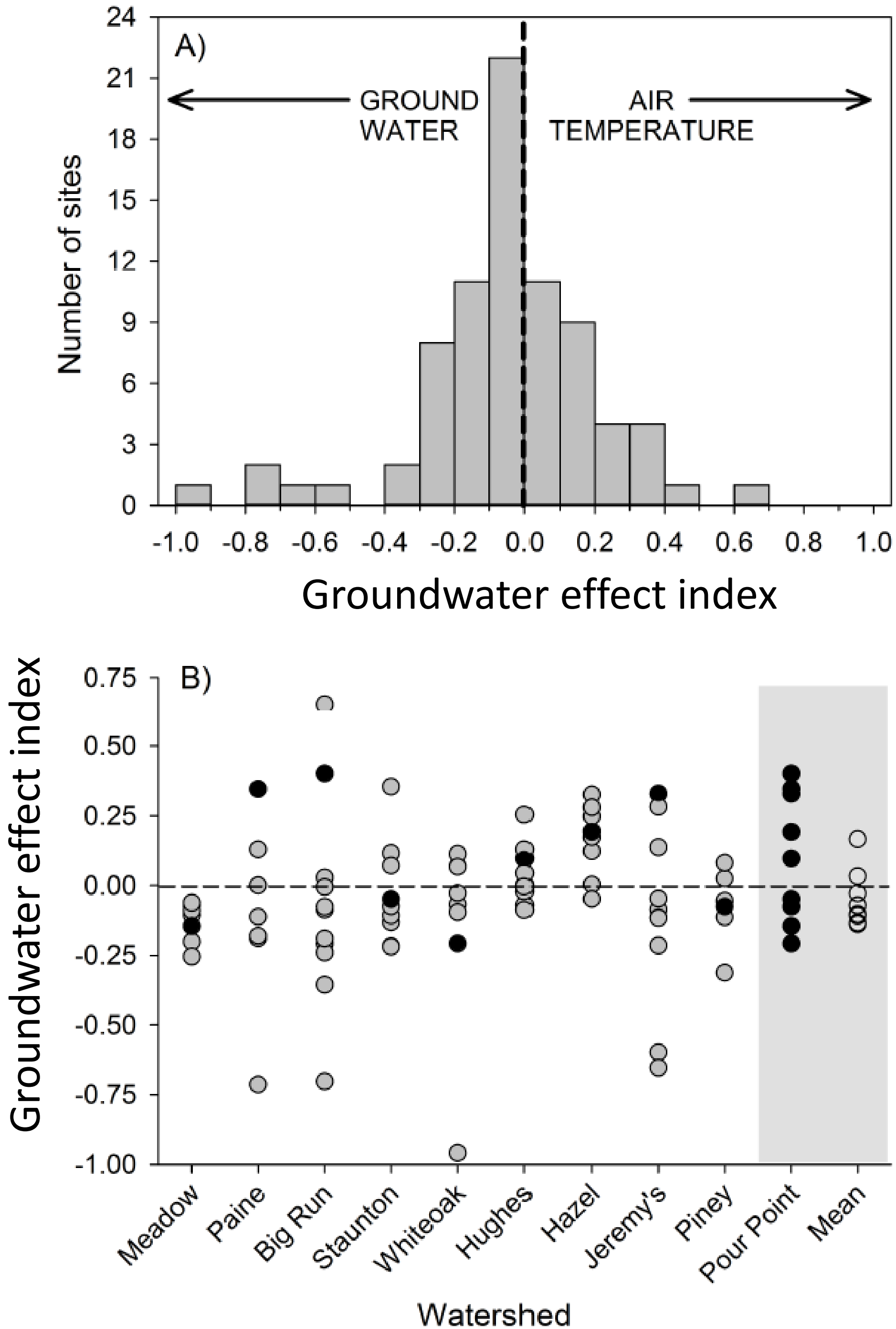




2-term linear models for stream temperature

1. Mean daily air temperature (MDA)
2. Accumulated degree days (ADD): groundwater indicator

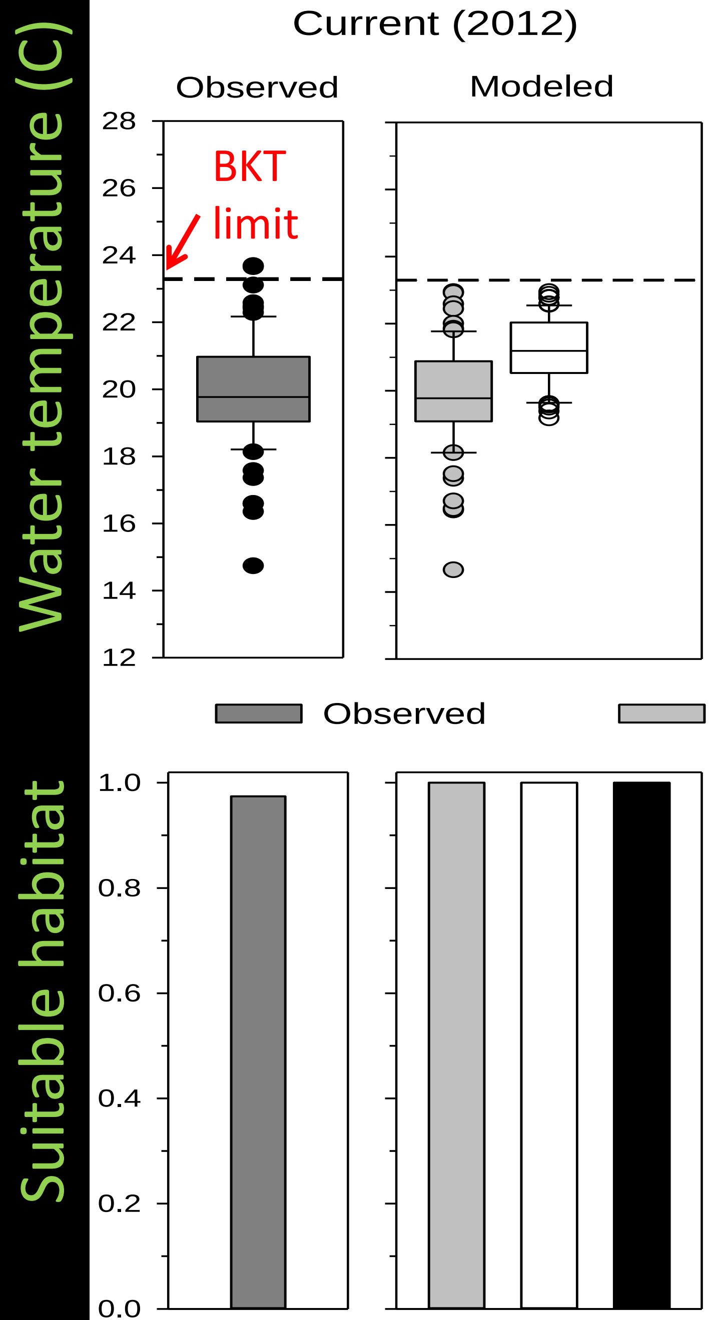
Improvements in model performance when including groundwater term (ADD).



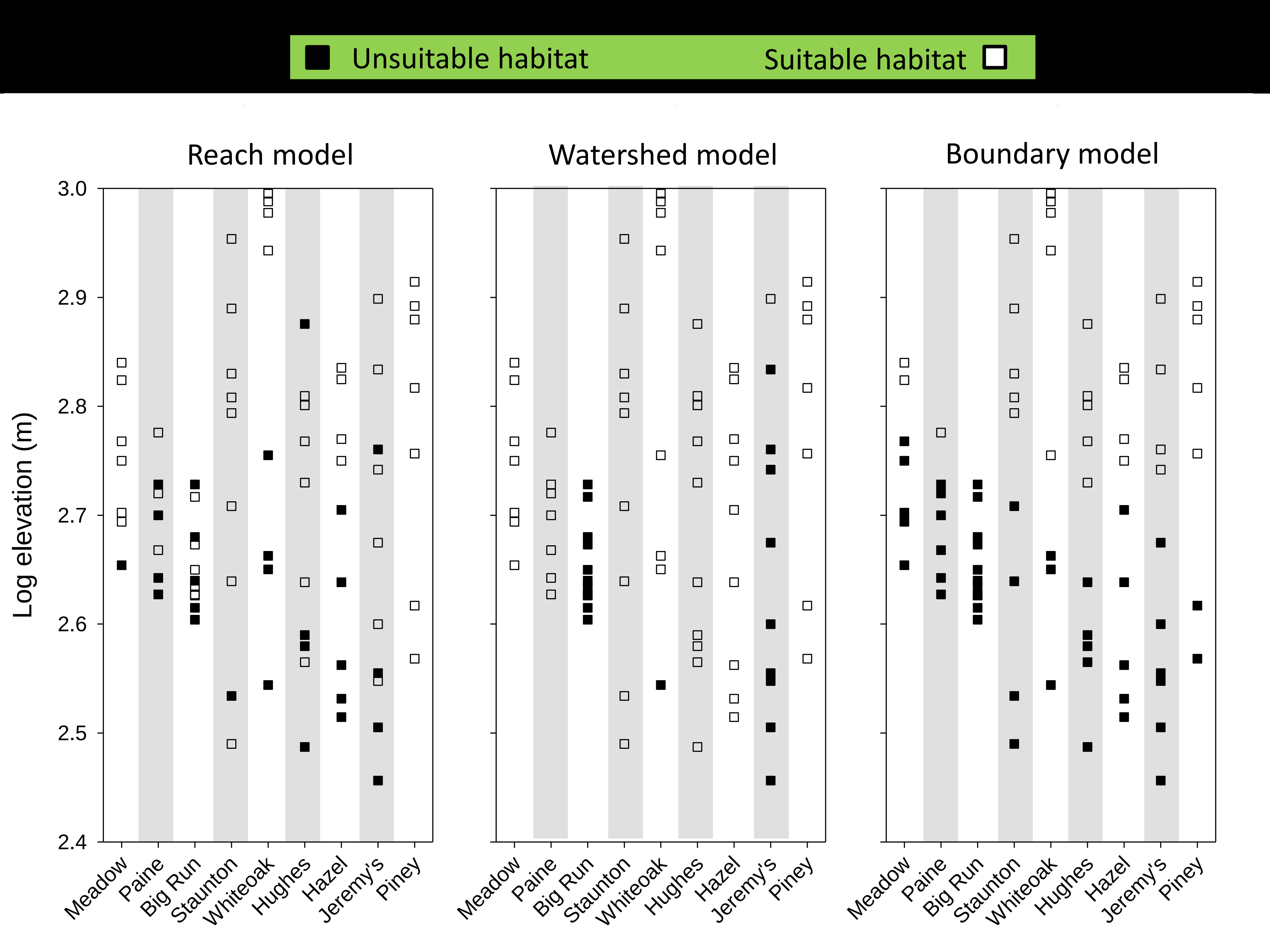
Index of groundwater vs. air temperature controls

ratio of standardized model coefficients

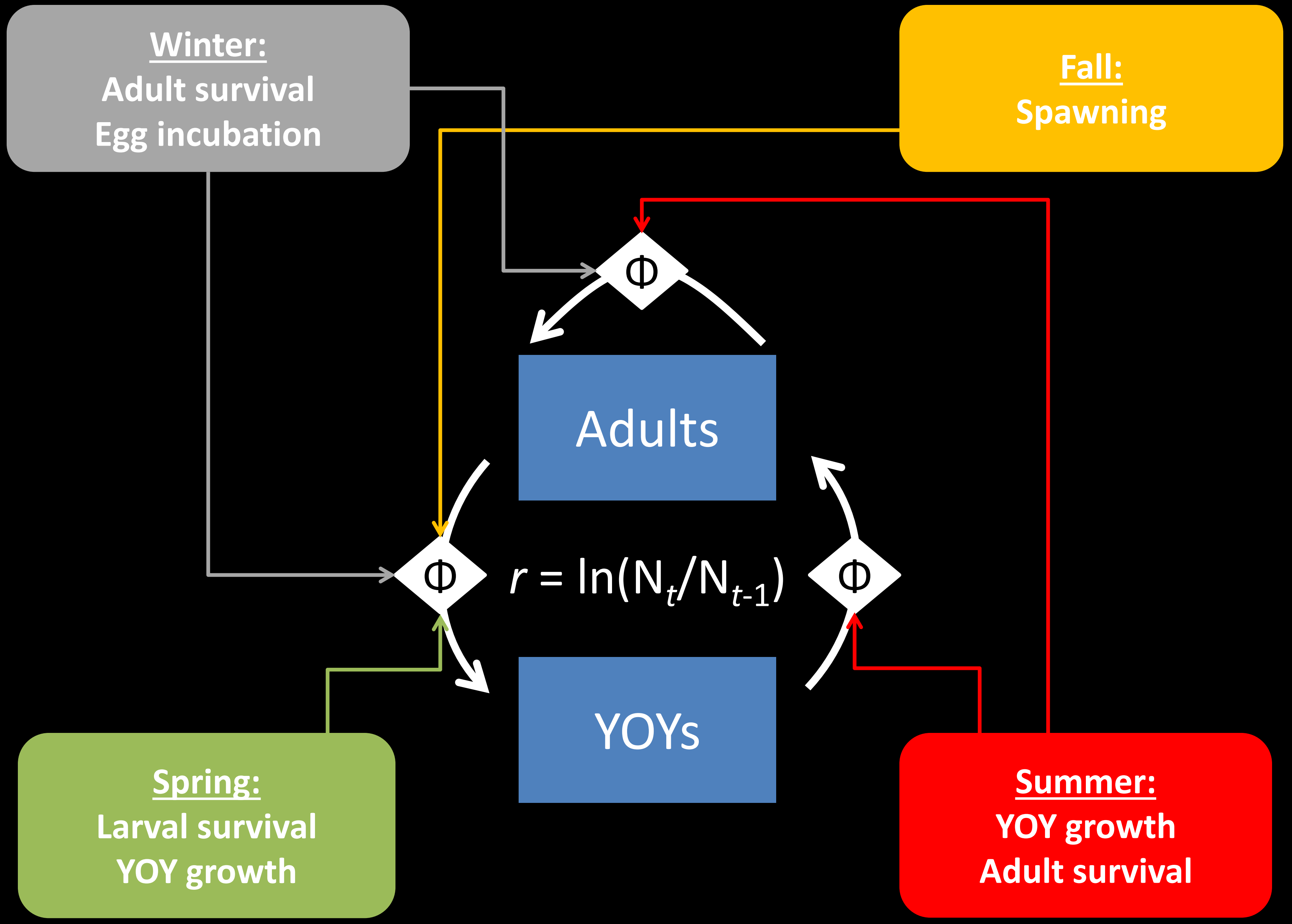
As much variation within HUC12 watersheds as between them



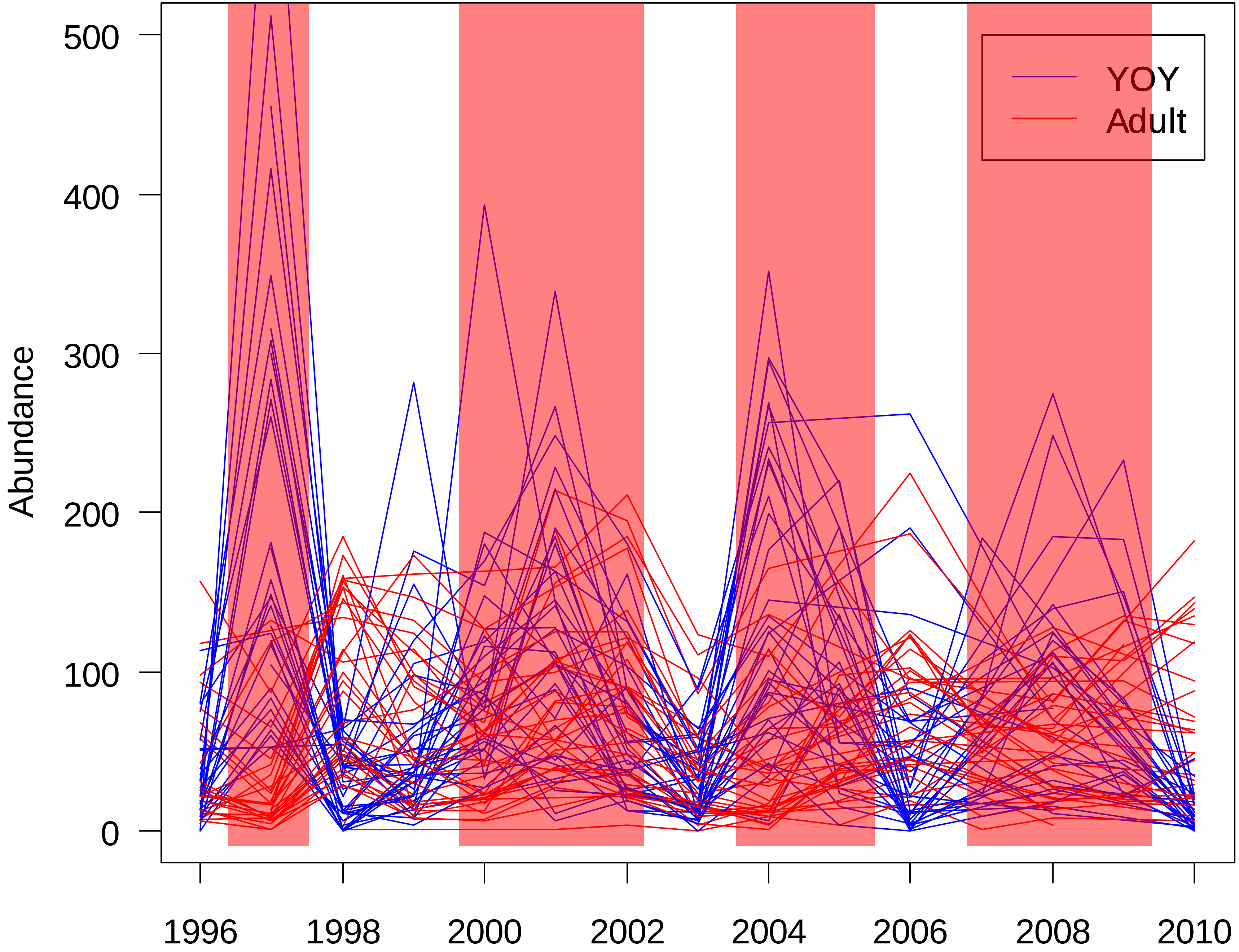
Water temperature (C)
Suitable habitat
Current (2012)
Observed
Modeled
BKT
limit
28
26
24
22
20
18
16
14
12
Observed
1.0
0.8
0.6
0.4
0.2
0.0


Unsuitable habitat
Suitable habitat
Reach model
Watershed model
Boundary model
Log elevation (m)
3.0
2.9
2.8
2.7
2.6
2.5
2.4
Meadow
Paine
Big Run
Staunton
Whiteoak
Hughes
Hazel
Jeremy's
Piney

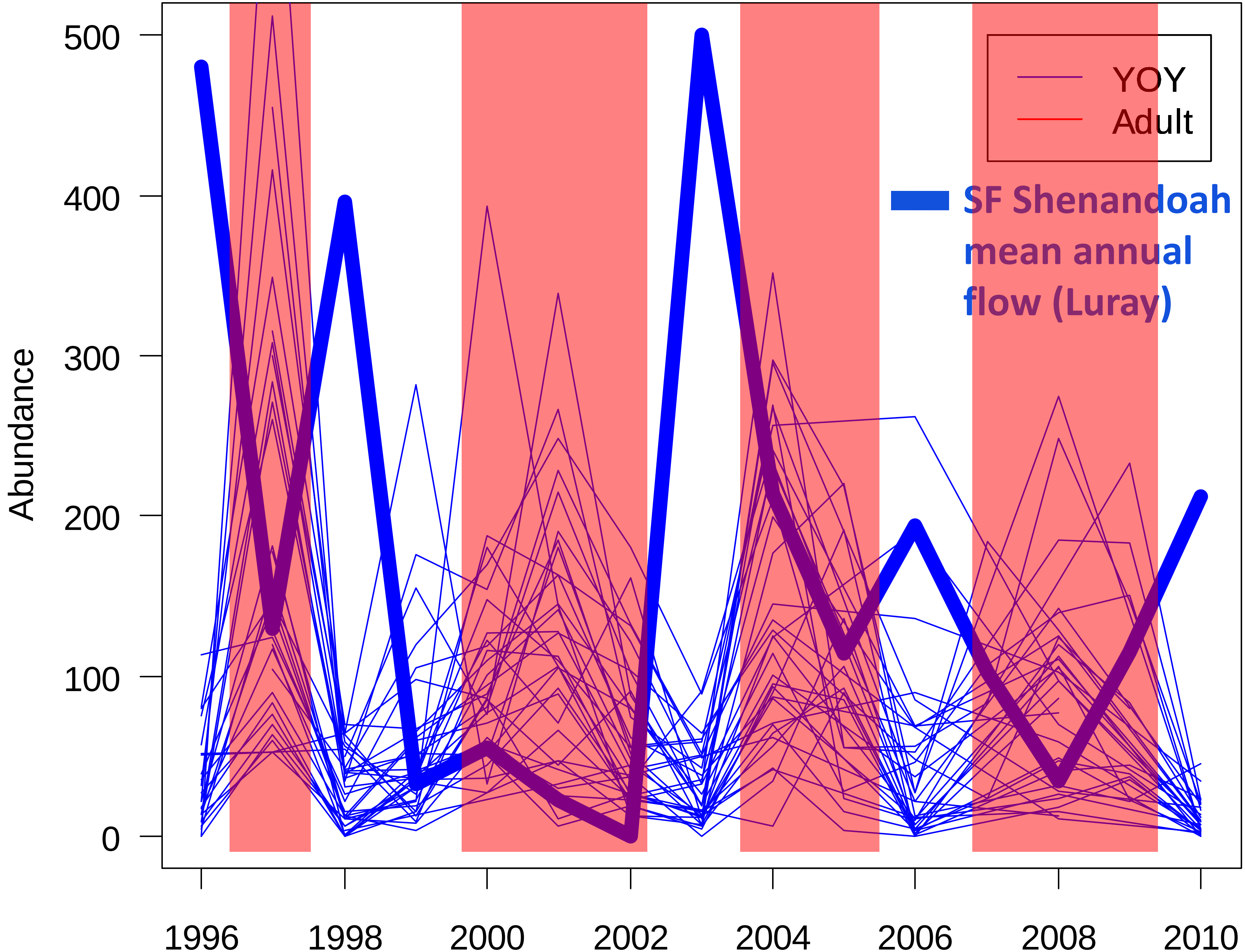
Modeling brook trout abundance


Winter:
Adult survival
Egg incubation
Fall:
Spawning
Adults
r = ln(N_t/N_t-1)
YOYs
Spring:
Larval survival
YOY growth
Summer:
YOY growth
Adult survival

Interannual variation with spatial synchrony



Importance of flow for YOY abundance



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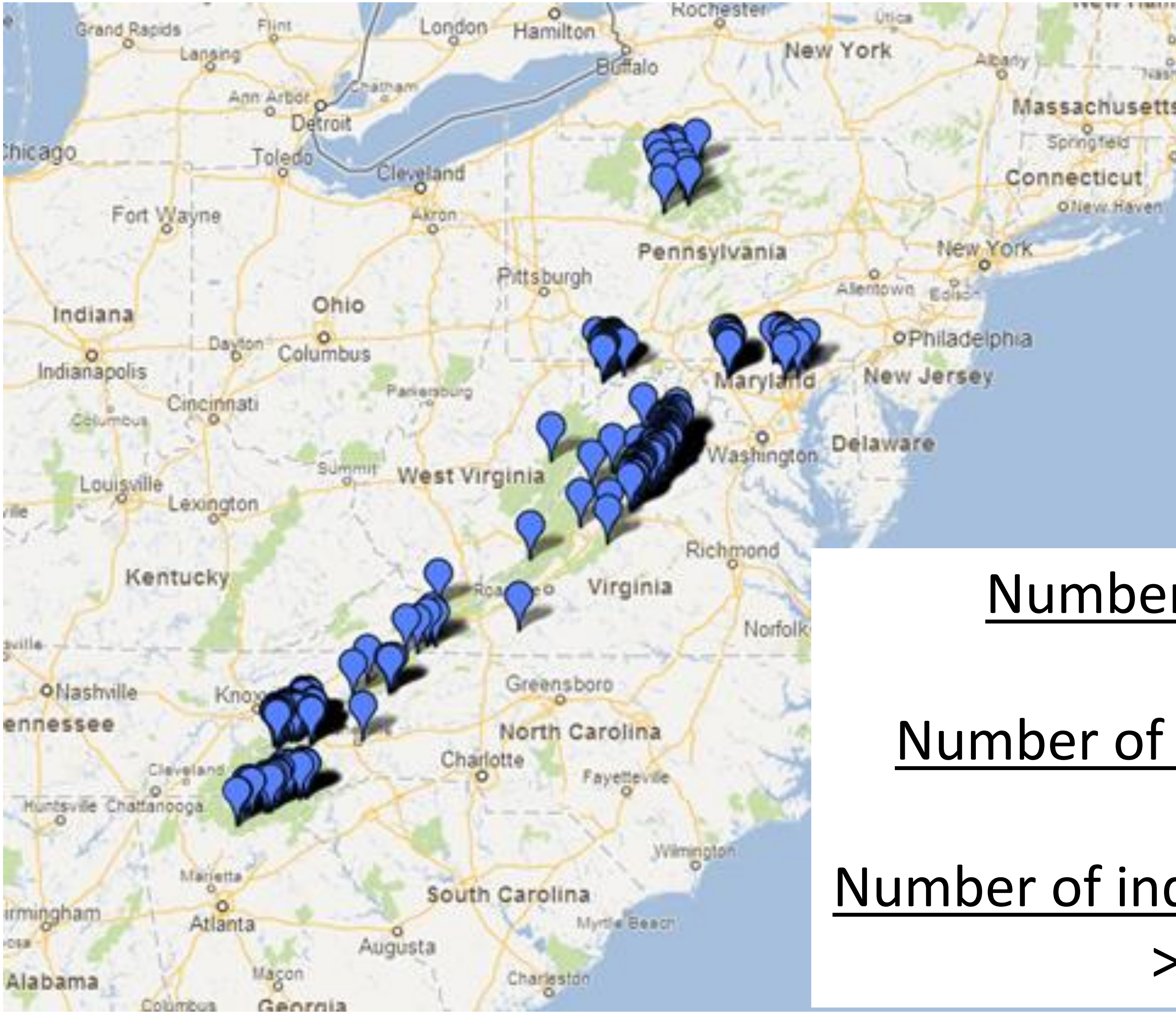


<u>Number of sites:</u>

> 350

<u>Number of samples:</u>

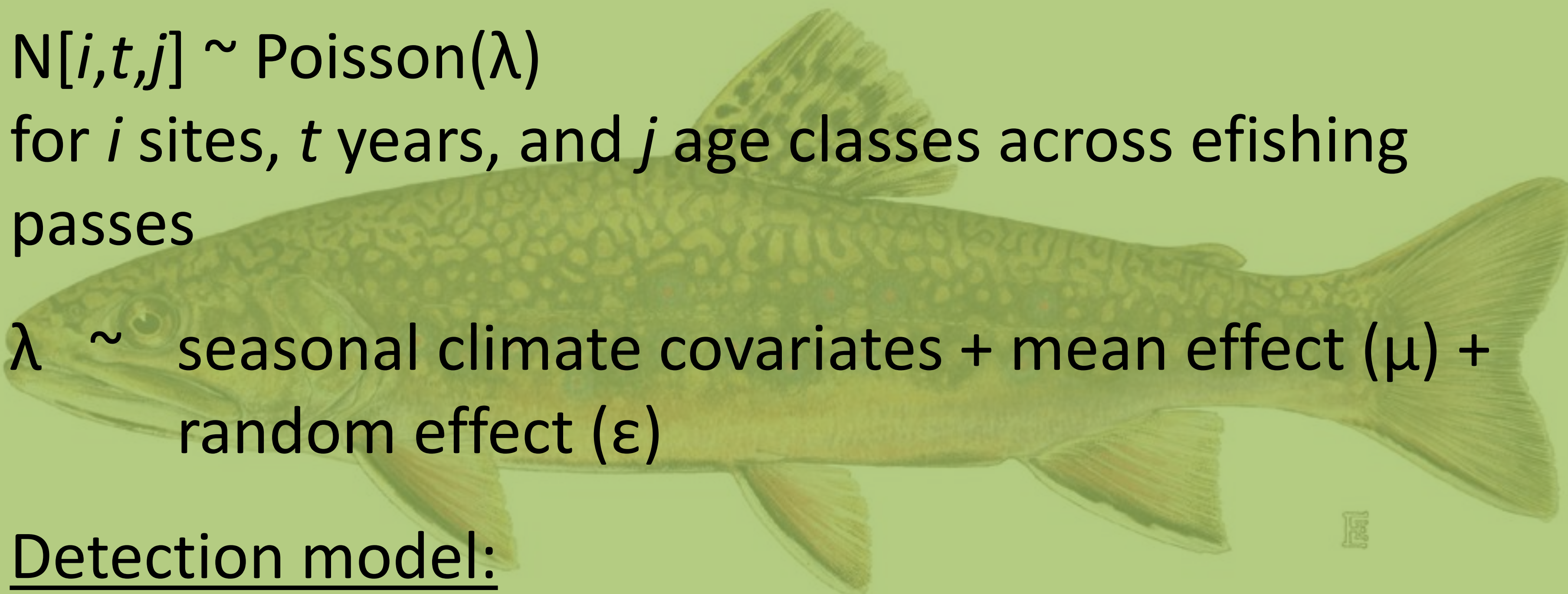
3205

<u>Number of individuals:</u>

> 250,000

Modeling brook trout abundance: Hierarchical Bayesian Models (N-mixture) in JAGS/R

<u>Process model:</u>



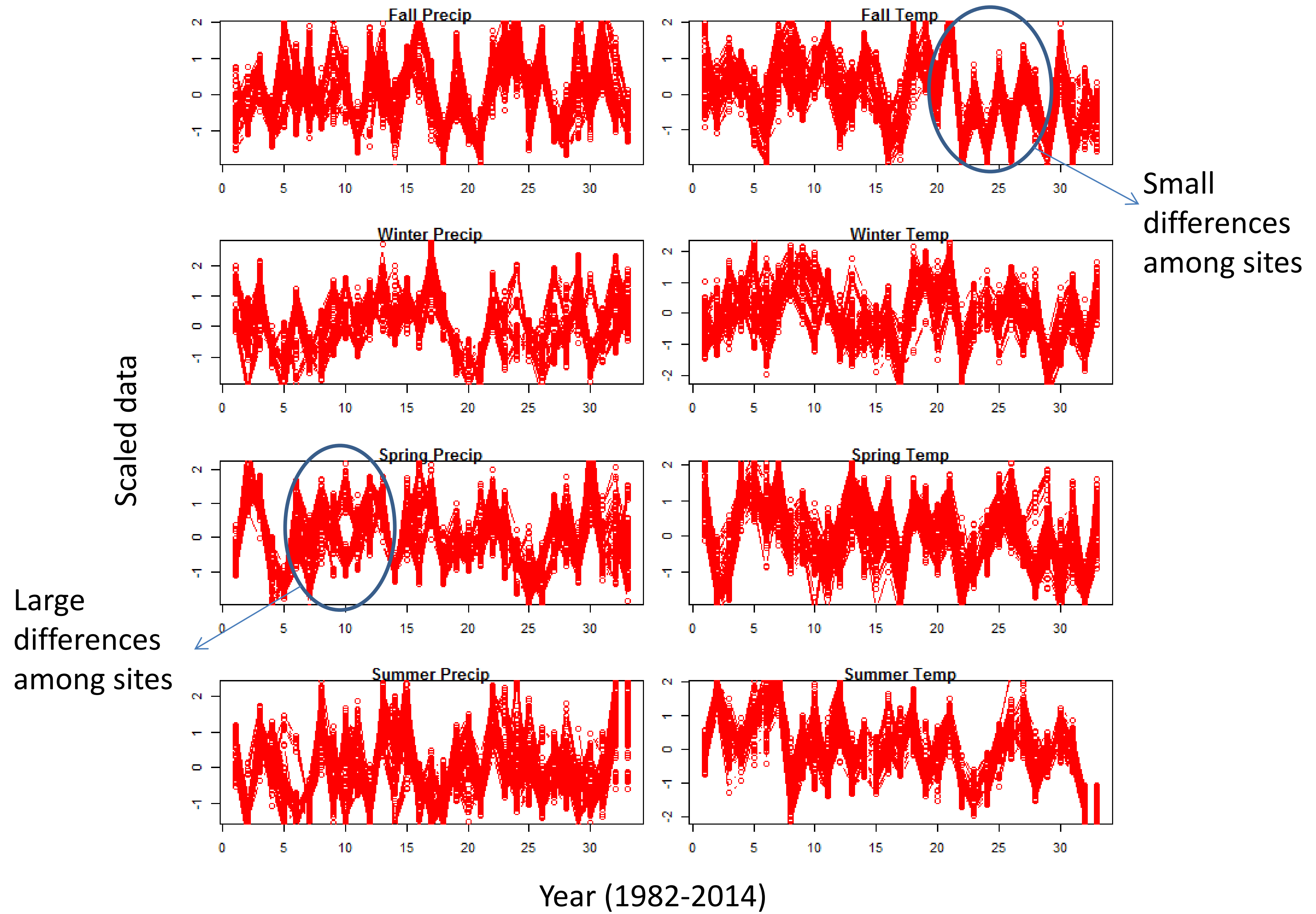
$N[i,t,j] \sim \text{Poisson}(\lambda)$
for *i* sites, *t* years, and *j* age classes across efishing passes

$\lambda \sim$ seasonal climate covariates + mean effect (μ) + random effect (ε)

<u>Detection model:</u>

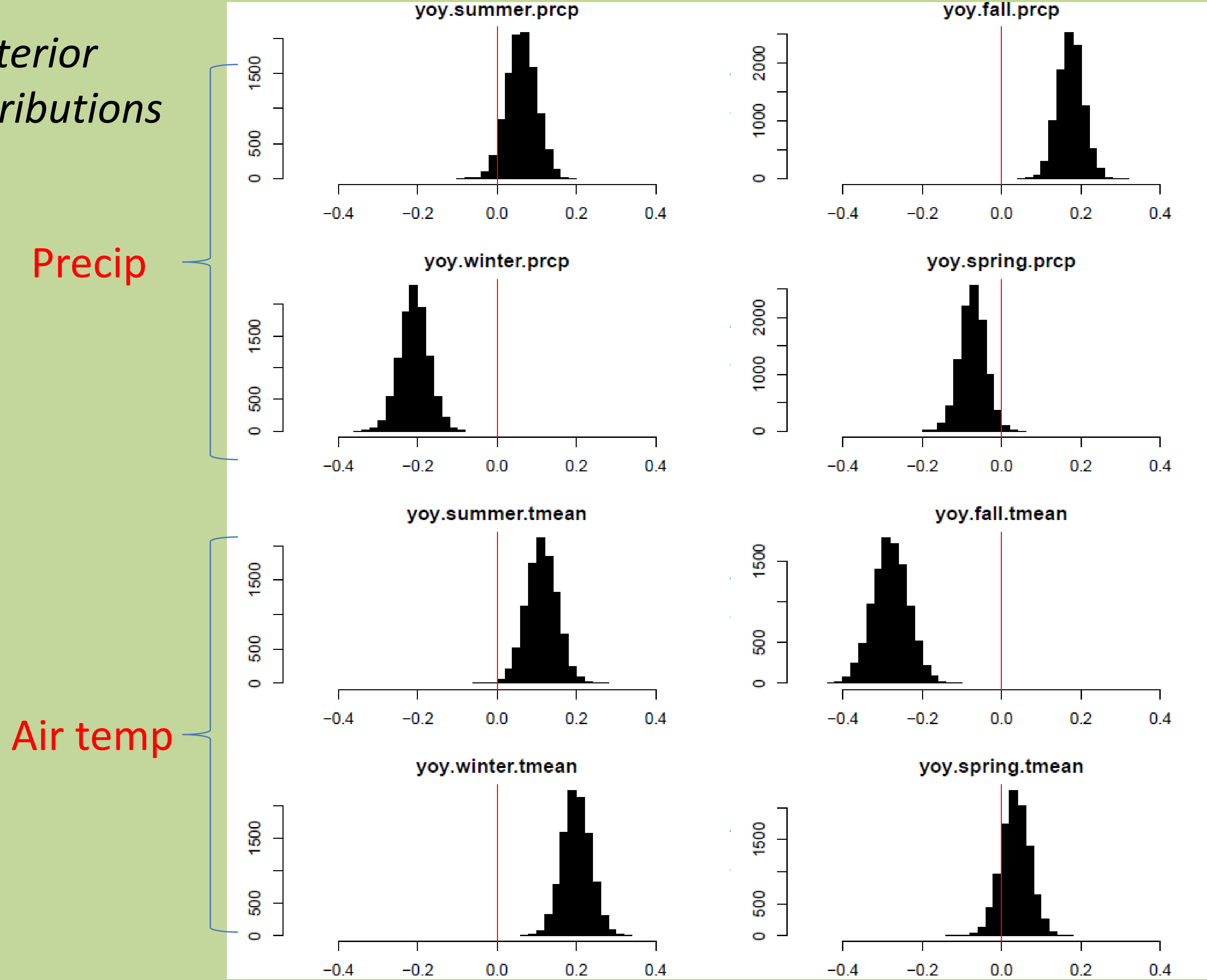
$y[i,t,j] \sim \text{Binomial}(N[i,t,j],\ p)$

$p \sim$ sampling day-of-year effect + prior 7-d precip effect



Fall Precip
Fall Temp
Winter Precip
Winter Temp
Spring Precip
Spring Temp
Summer Precip
Summer Temp
Scaled data
Year (1982-2014)
Small differences among sites
Large differences among sites

Posterior distributions



Effects of seasonal climate variation on abundance

For 95% Credible Intervals excluding zero:

	Precipitation	
	YOY	**Adult**
Fall	Positive	-
Winter	Negative	-
Spring	Negative	Negative
Summer	-	-

	Temperature	
	YOY	**Adult**
Fall	Negative	Positive
Winter	Positive	Negative
Spring	-	-
Summer	Positive	-

Inferences

YOY abundance generally more responsive to seasonal climate variation than adult abundance

Highest YOY abundance scenario: wet/cold fall + dry/warm winter + dry spring + warm summer

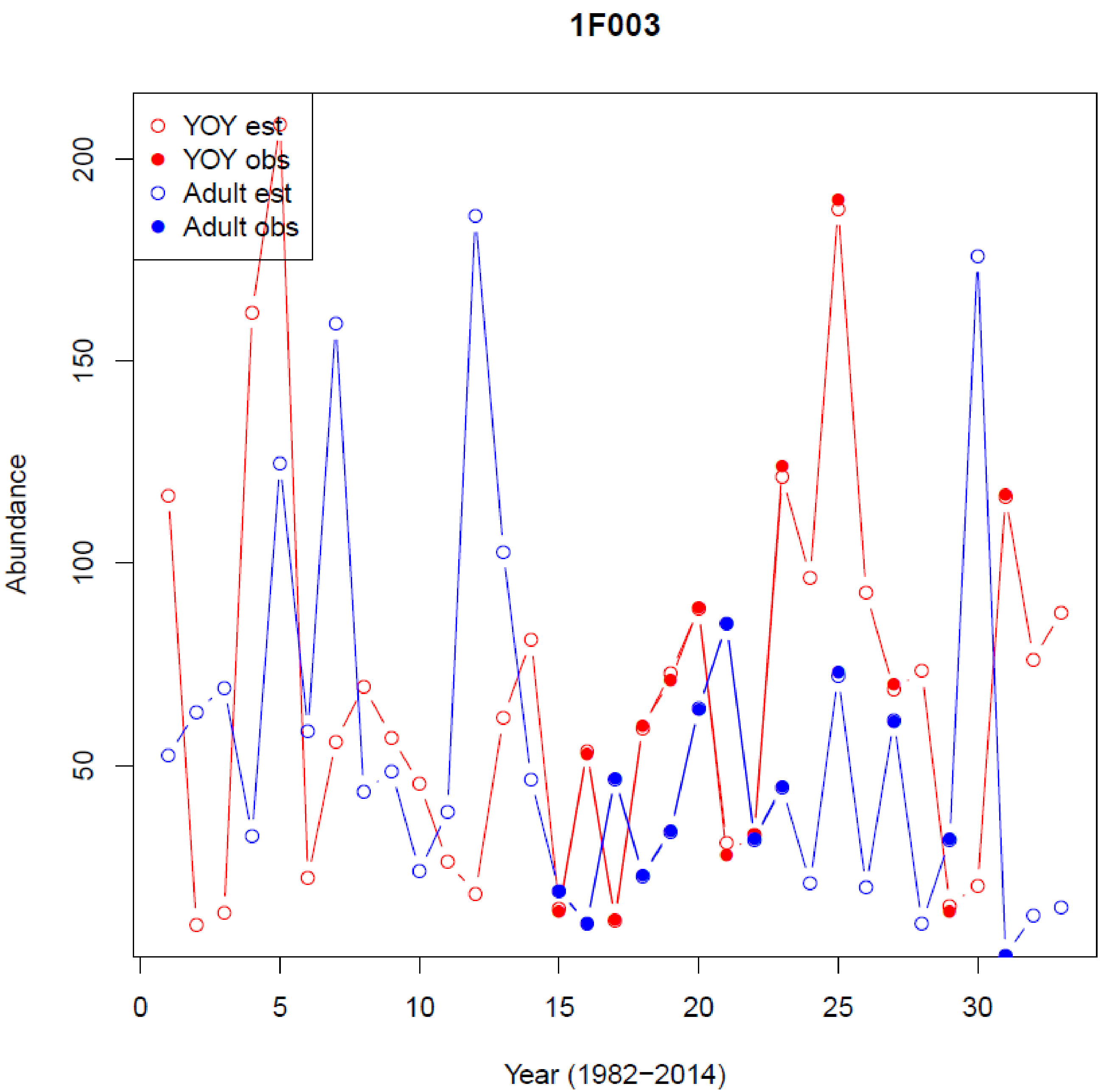
Lowest YOY abundance scenario: dry/warm fall + wet/cold winter + wet spring + cold summer

Highest adult abundance scenario: warm fall + cold winter + dry spring

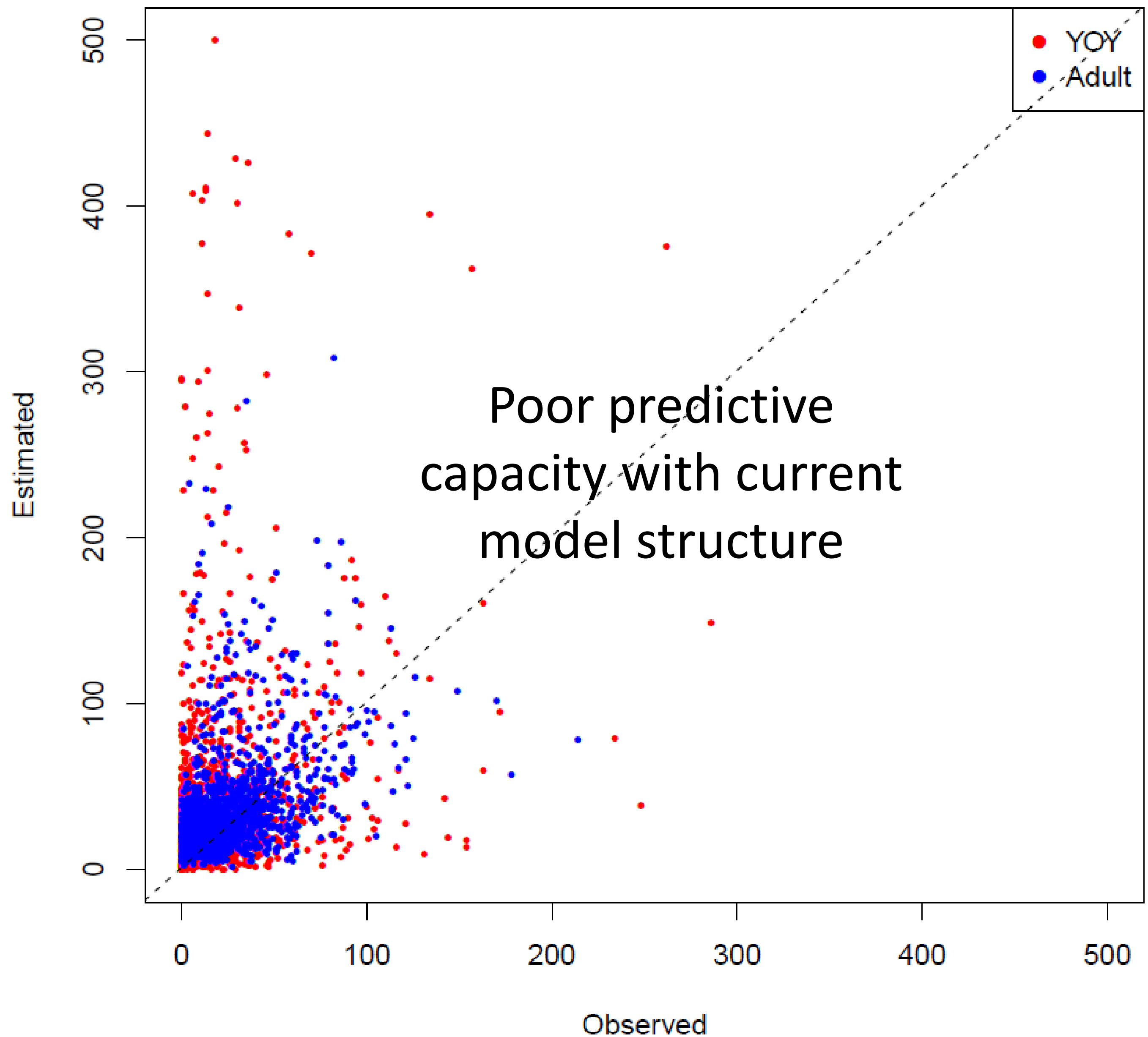
Lowest adult abundance scenario: cold fall + warm winter + wet spring

Some seasonal climate effects have opposite effects on YOY and adult N: fall and winter temperature

Observed vs estimated abundance



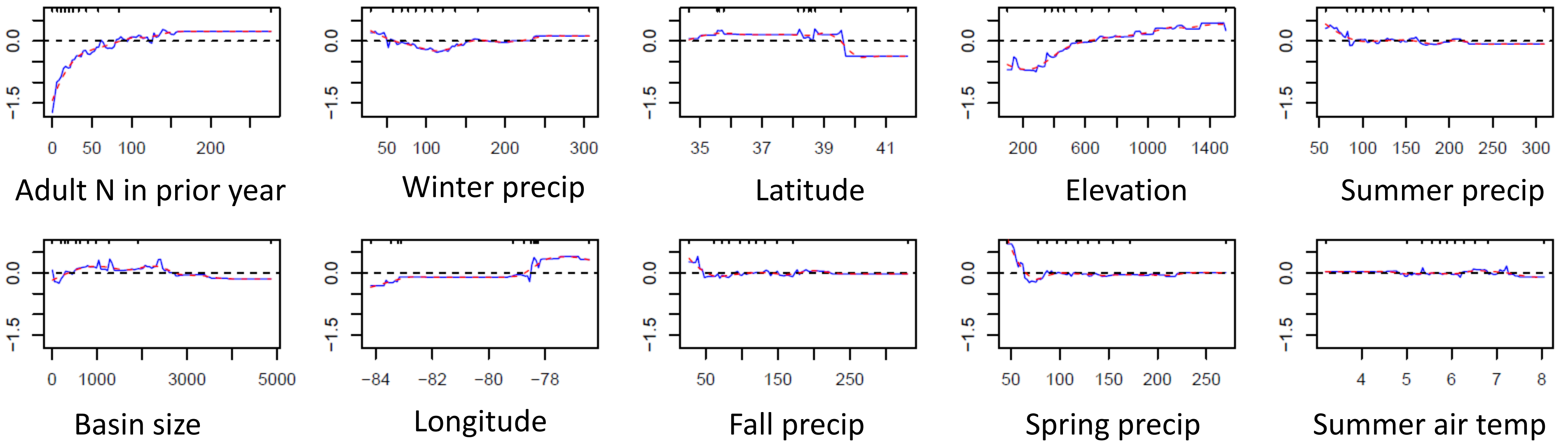
Observed vs. estimated N: 10% hold-out validation



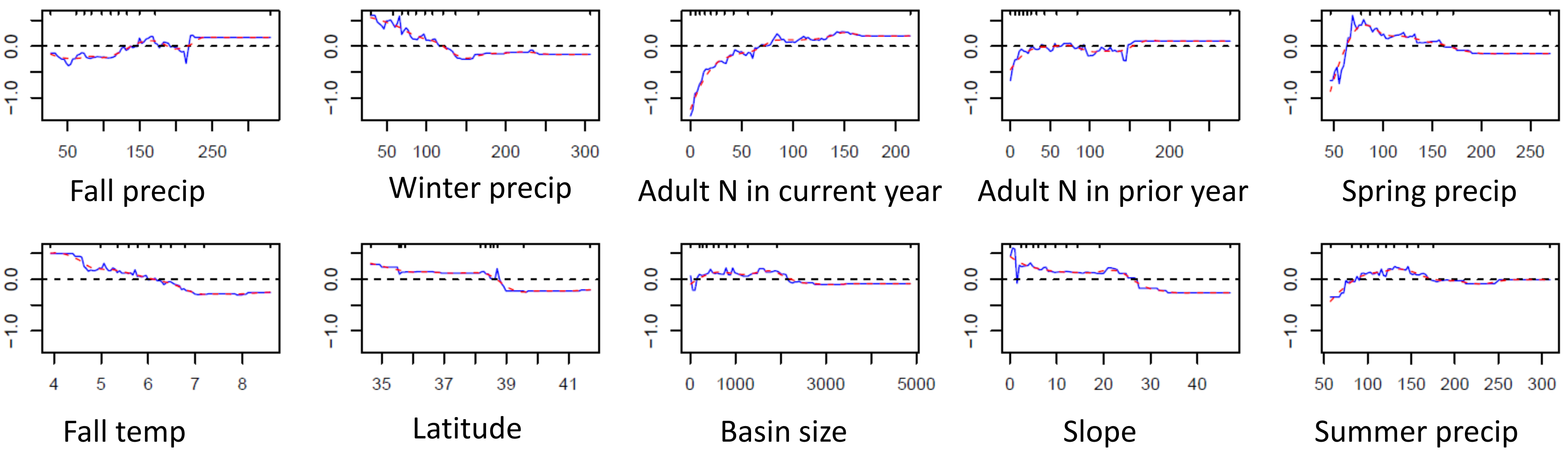
Boosted Regression Trees

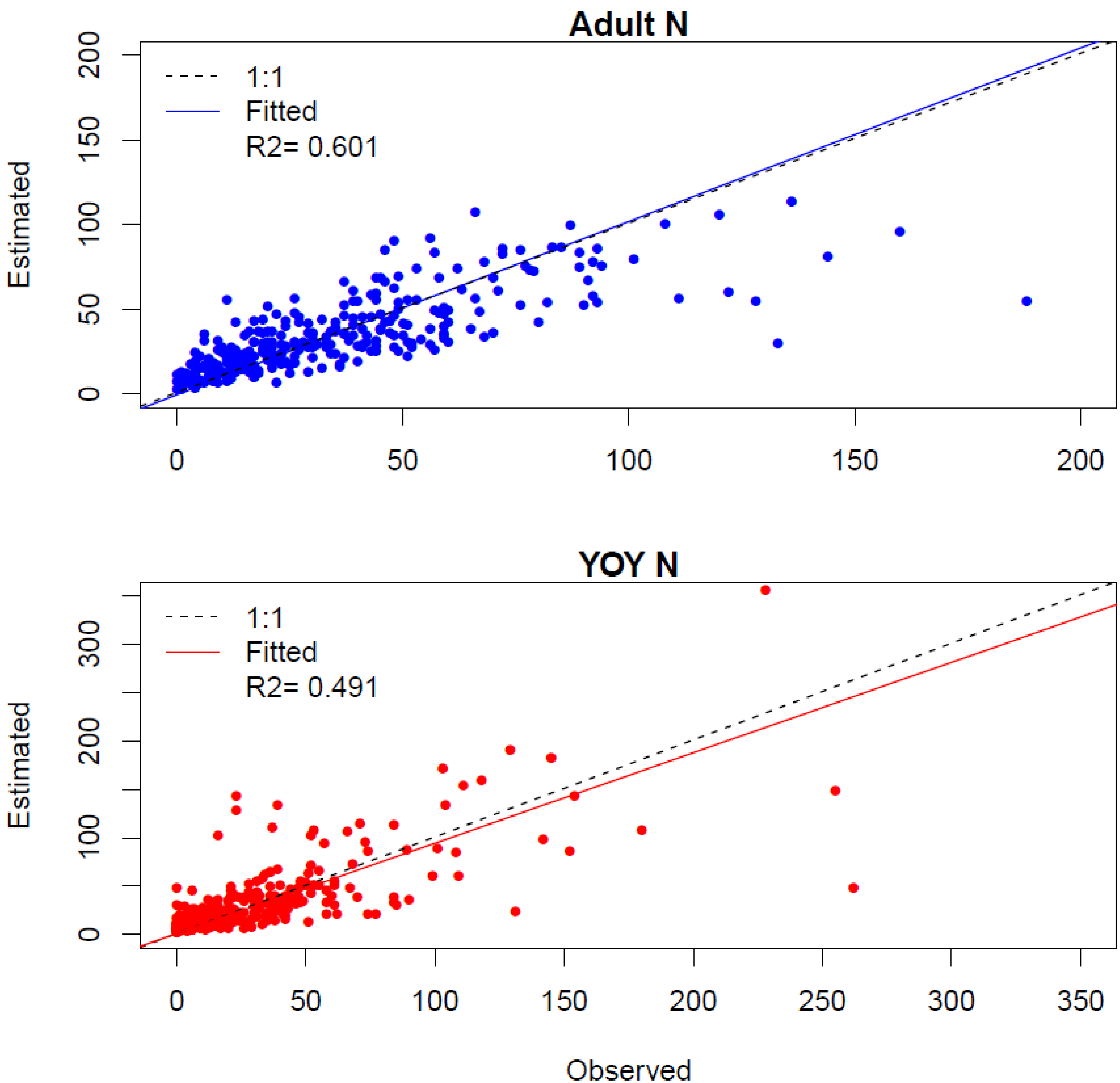
- Library "gbm" in R and scripts from Elith et al. (2008)
- Internal cross-validation for model fitting
- Requires optimization for learning rate and tree complexity (interactive effects)
- Variables including density-dependent parameters (re: predation and competition) and density-independent parameters (re: temperature and precipitation)

Modeling brook trout abundance: adults

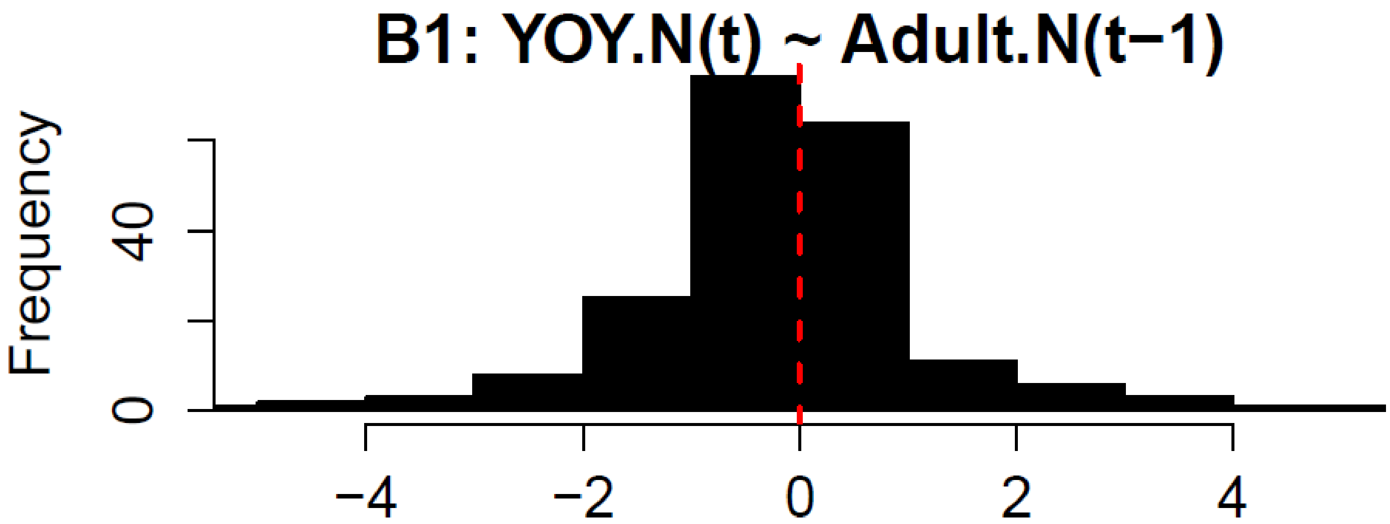


Modeling brook trout abundance: YOYs

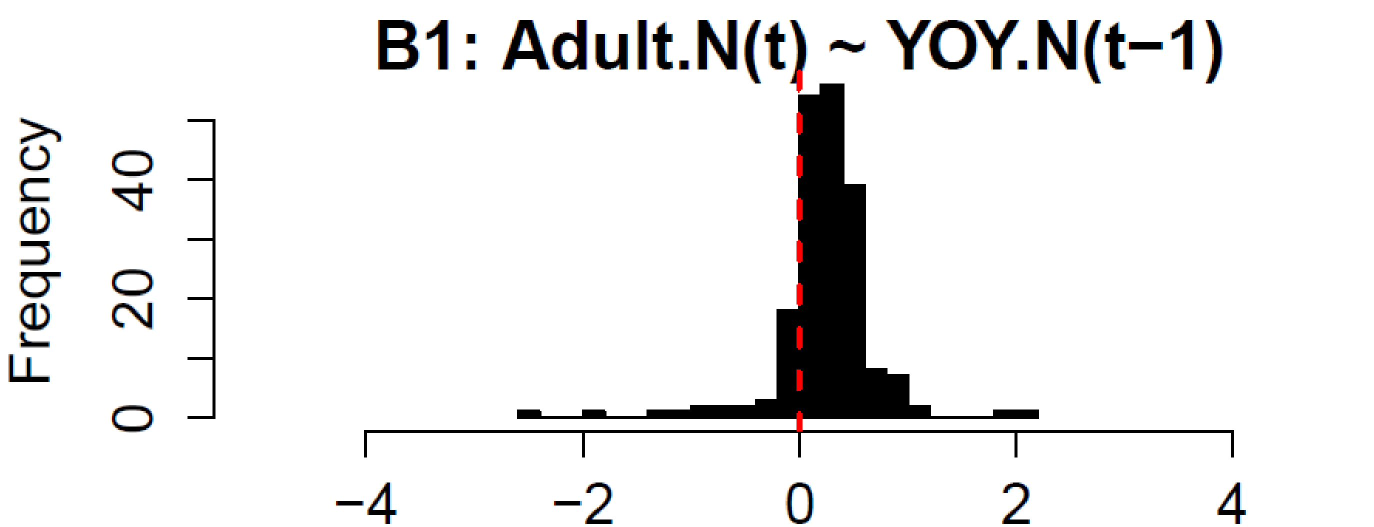




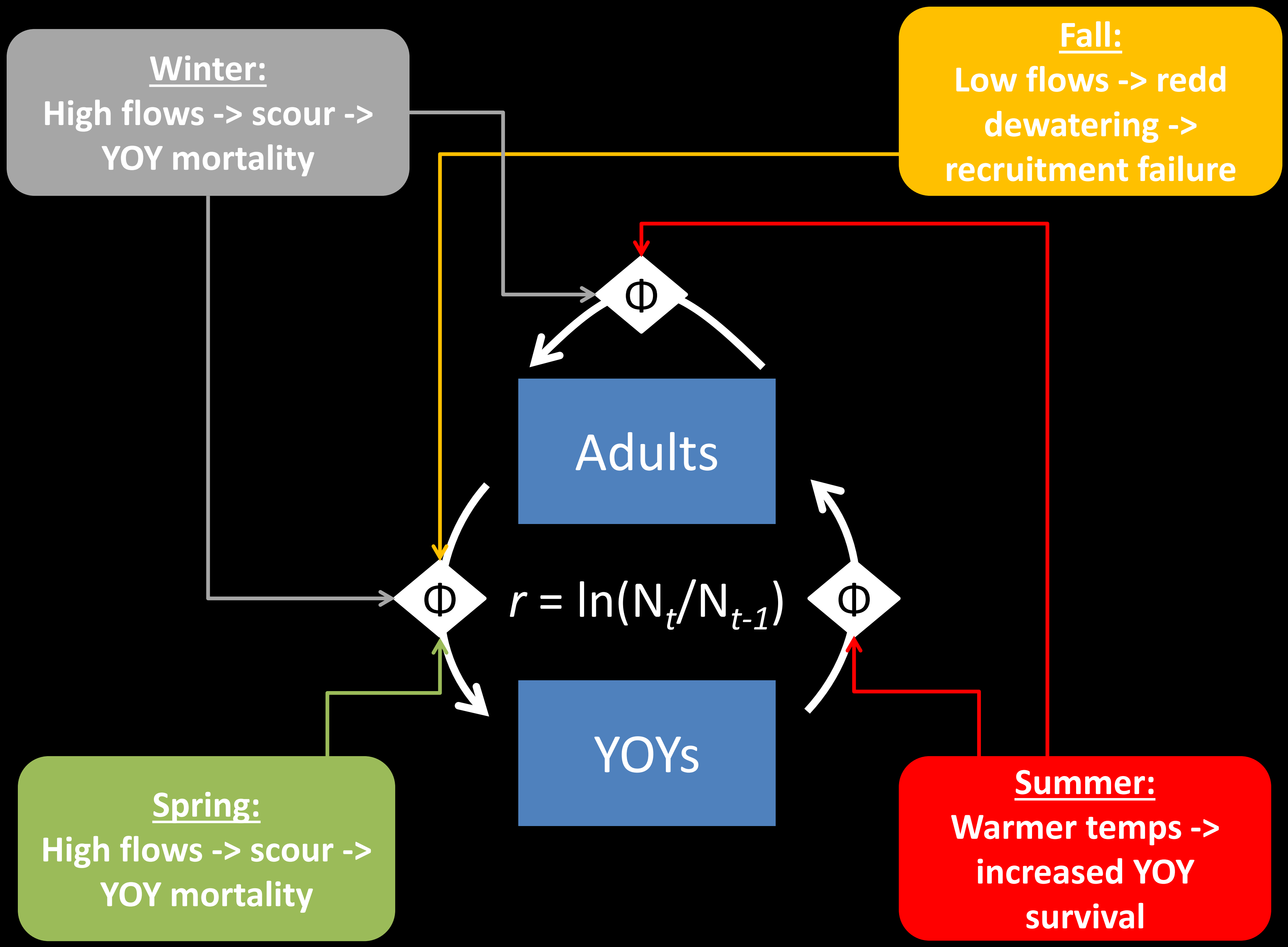
10% hold-out validation



Random effects of adult abundance on recruitment



Positive effects of YOY abundance on adult abundance in following year


Winter:
High flows -> scour -> YOY mortality
Fall:
Low flows -> redd dewatering -> recruitment failure
Φ
Adults
Φ
$r = \ln(N_t/N_{t-1})$
Φ
YOYs
Spring:
High flows -> scour -> YOY mortality
Summer:
Warmer temps -> increased YOY survival

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