Conservation of *Rana boylii*

Ryan Peek
UC Davis - Center for Watershed Sciences
rapeek@ucdavis.edu

Sarah J. Kupferberg
Questa Engineering
skupferberg@gmail.com

ACKNOWLEDGEMENTS

Thx to many collaborators!

Eel : Alessandro Catenazzi –esp. photos!

M. Power, P. Steel, K. Grief, S. Temple, C. Bailey, M. Poteet, J. Finlay, T. Blacic, V. Vredenburg, K. Fausch, J. Walker, S. Houssein, R. Doubledee, P. Bass, J. Choy, S. Khandwala, S. Madden, A. Osterback, A. Lind, W. Palen, S. Yarnell

Alameda : S. Bobzien, M. Grefsrud, A. Adams

Feather : Kevin Wiseman,

Karla Marlow, Joe Drennan

Rob Leidy -- this photo

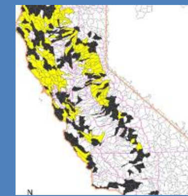
California Energy Commission

Center for Watershed Sciences

Michael Miller, Amy Lind, Brad Shaffer, Corey Luna, Sarah Mussulman, Sean O'Rourke, Sarah Yarnell, and folks from SYRCL, Sierra Streams!

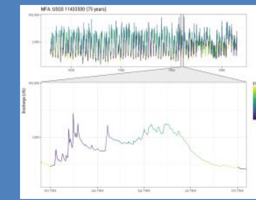
OVERVIEW

- 15-20 min segments
- Question / stretch breaks
- Larger discussion after last segment



1. Natural History

Where / when have they been?



2. Breeding Timing

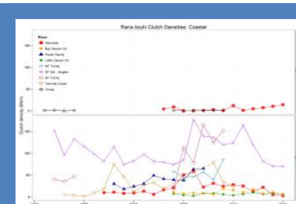
How does flow influence reproduction?

3. Ecology

What are interactions with other species?

4. Genetics

New methods to assess population genetic health?



5. Dynamics

What are recent population trends?

???

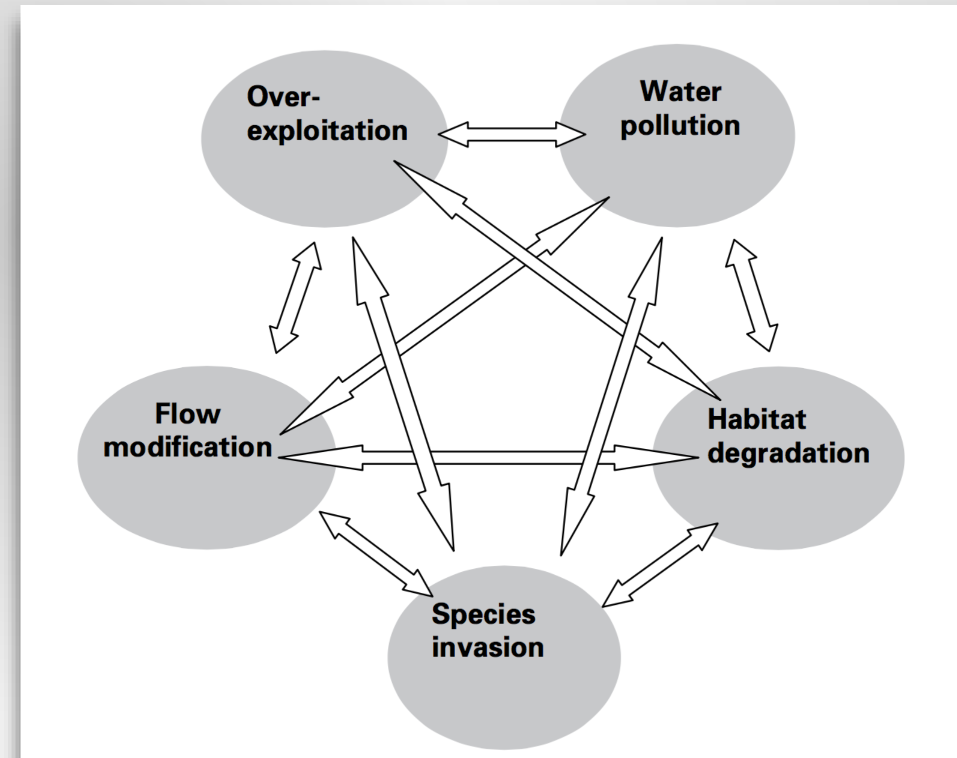
Conservation Outcomes

Rana boylii

- **Natural History**
- Breeding Timing & Plasticity
- Ecology
- Conservation Genetics
- Population Dynamics

Imperiled Freshwaters

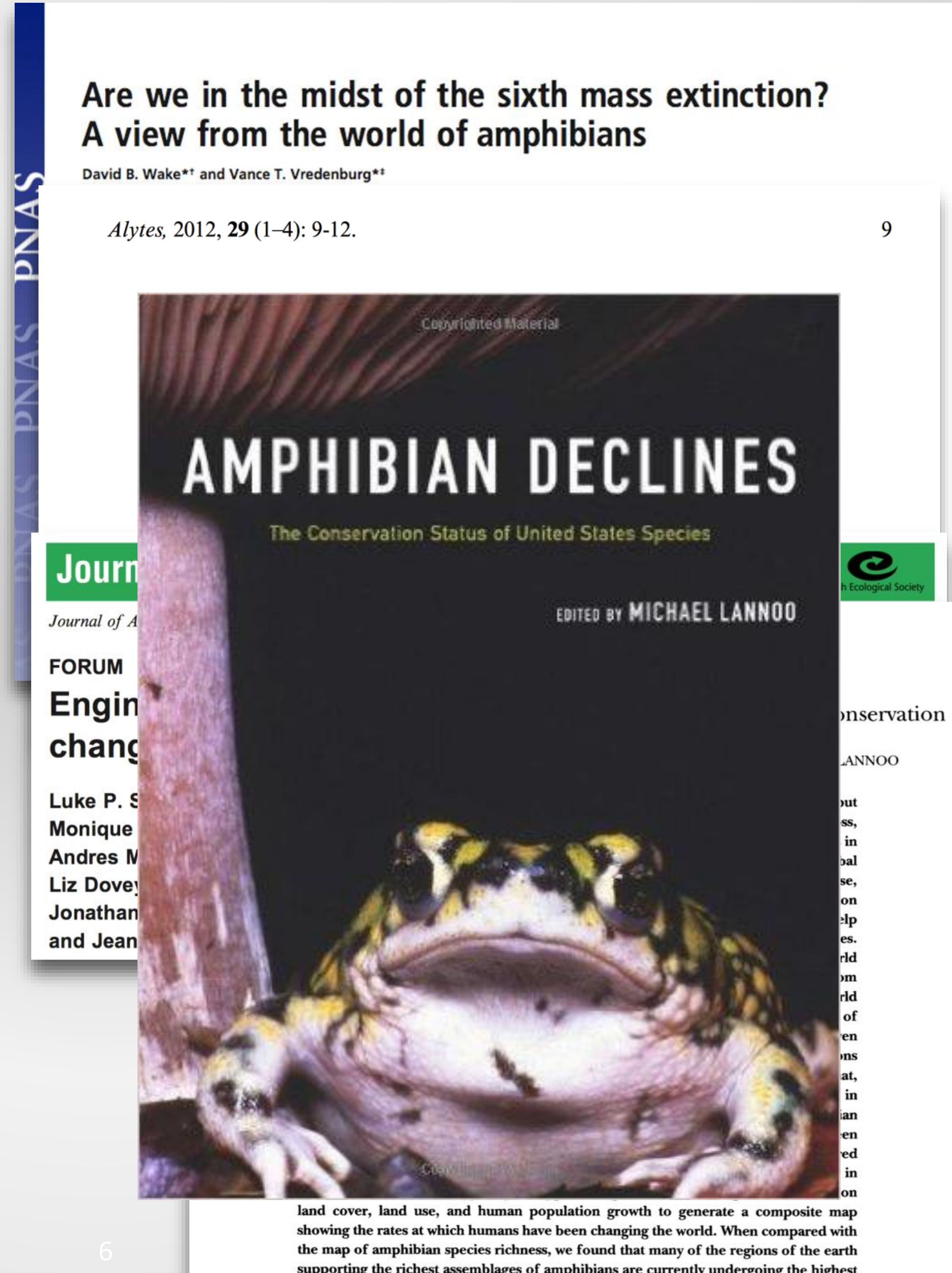
- Half the world's population lives within 20 km of a permanent river (Small and Cohen 1999)
- Projected mean extinction rates in freshwater organisms 5x greater than terrestrial (Ricciardi and Rasmussen 1999)



Dudgeon et al. 2006

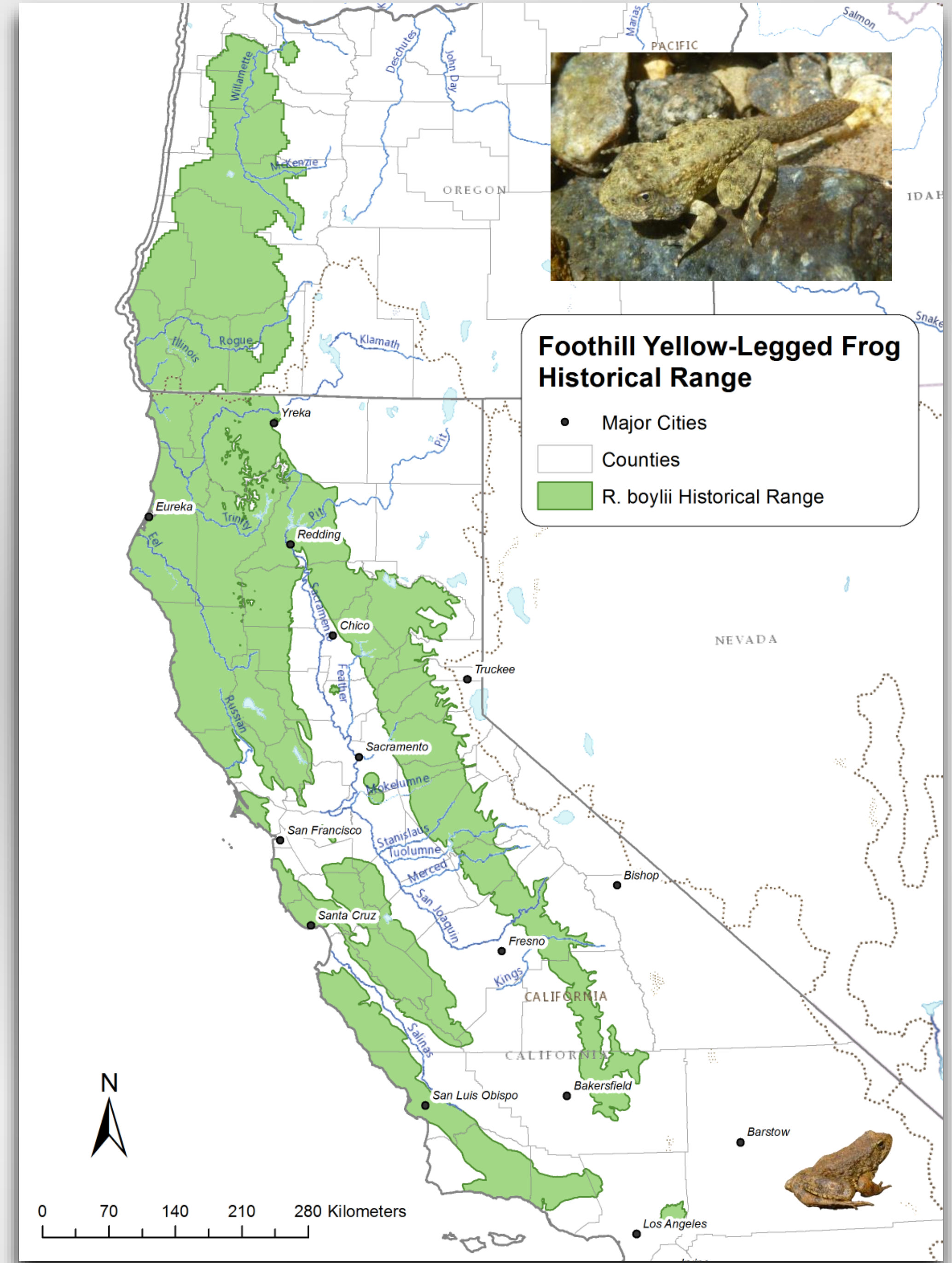
Amphibian Declines

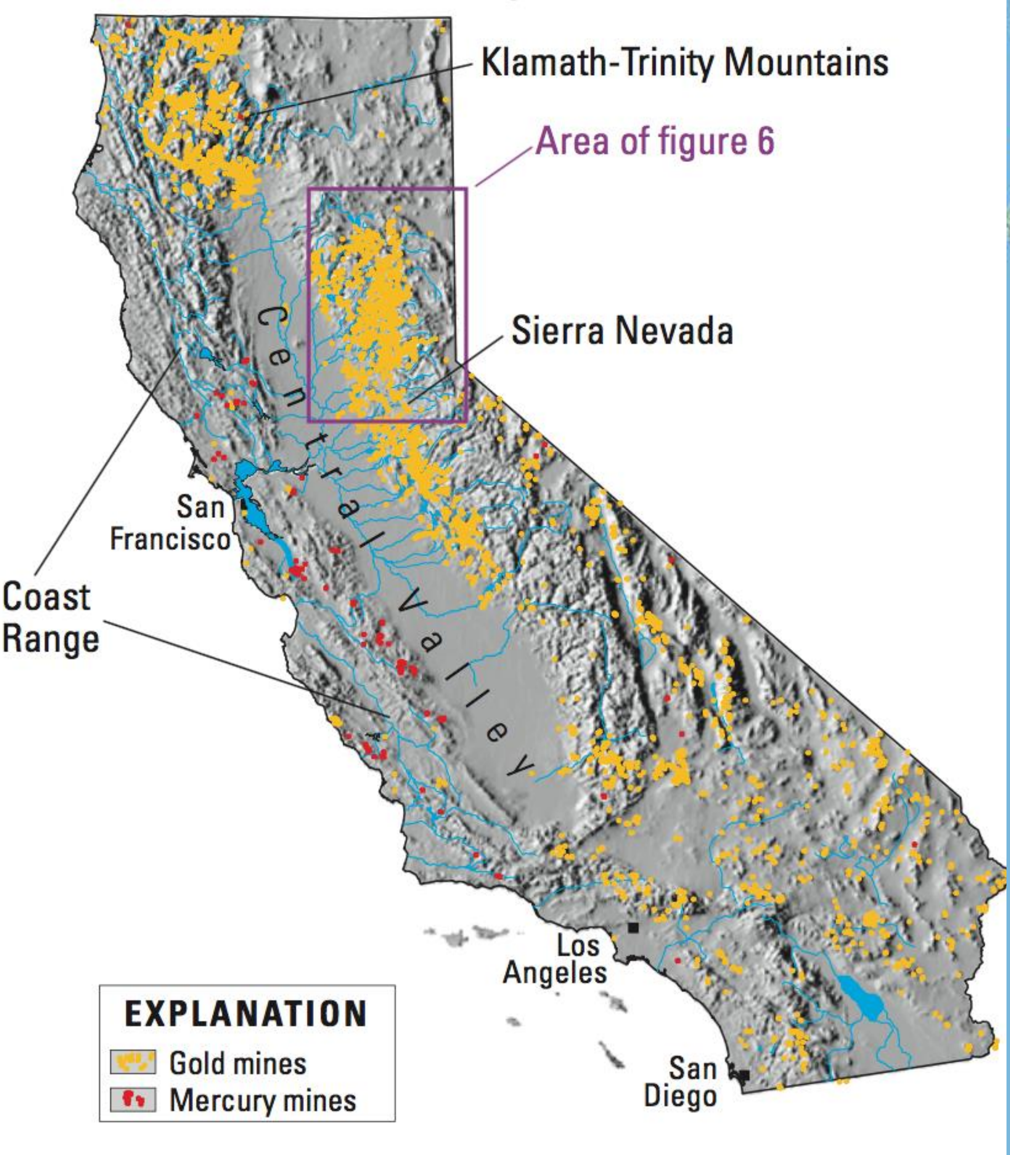
- Uniquely link aquatic and terrestrial ecosystems
- Have persisted through the last 4 mass extinctions
- Amphibian taxon are at greatest risk of extinction *(Stuart et al. 2004)*

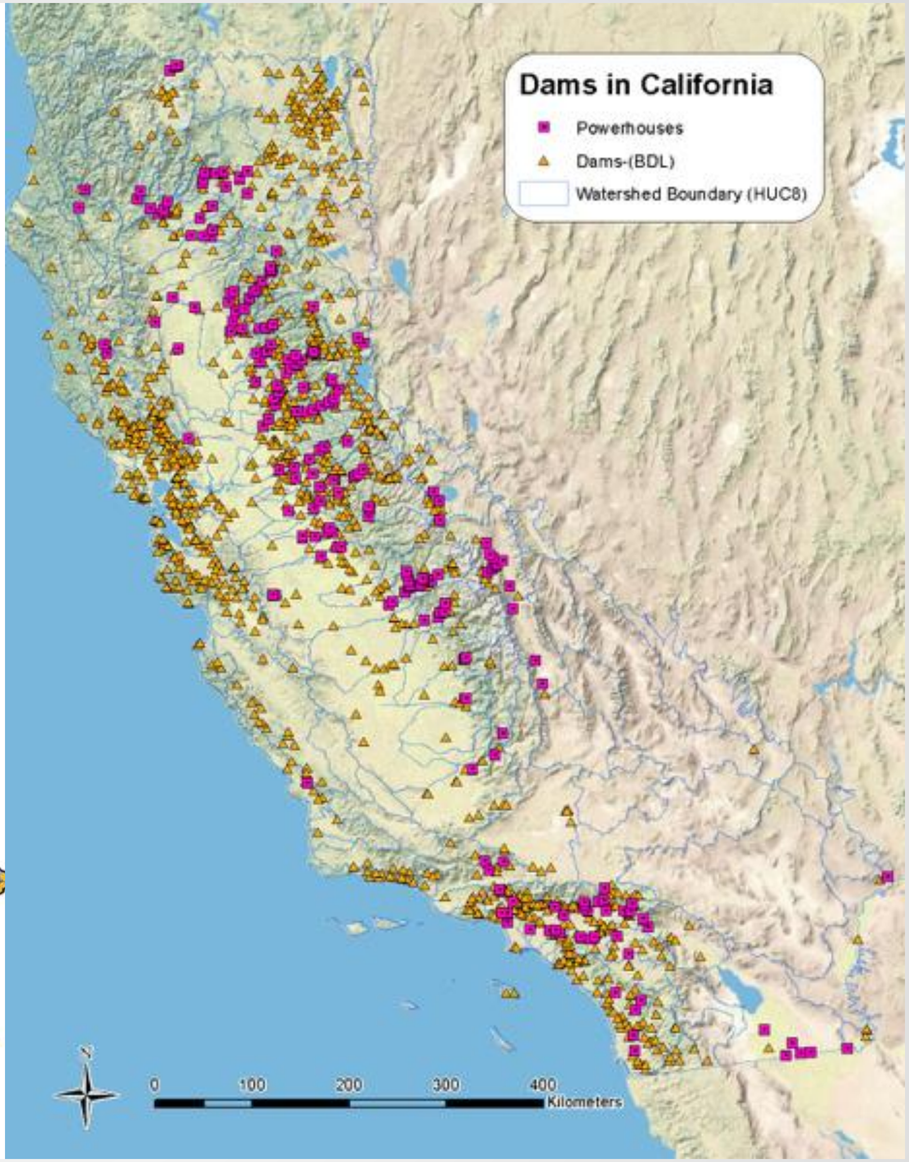


Rana boylii (Foothill yellow-legged Frog)

- Extant in CA and OR for ~5-8 million years *(Macey et al. 2001)*
- Obligate river breeding frog, uses wide range of habitat
- Has disappeared from over 50% of historical range *(Davidson et al. 2002)*



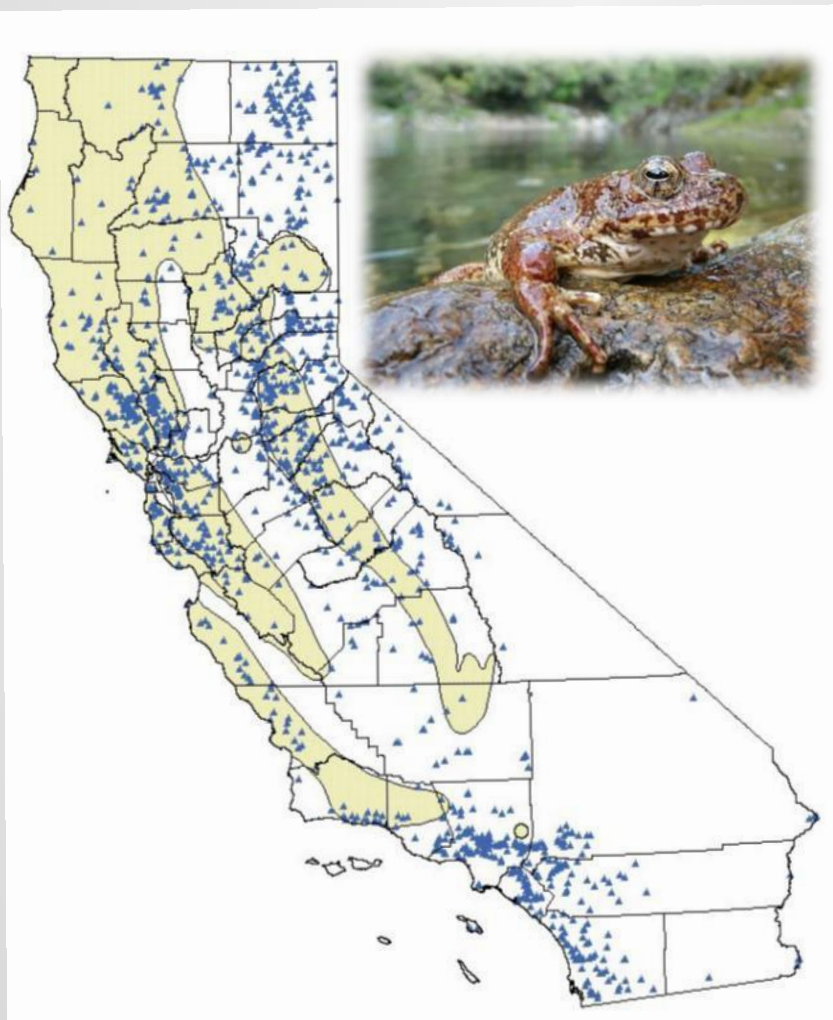




Hydraulic Mining (1850-1890s)

Damming of Rivers (~1930's on)

DAMS:
Range-wide changes (*Amy Lind 2005*)



Modern vs. historic locations

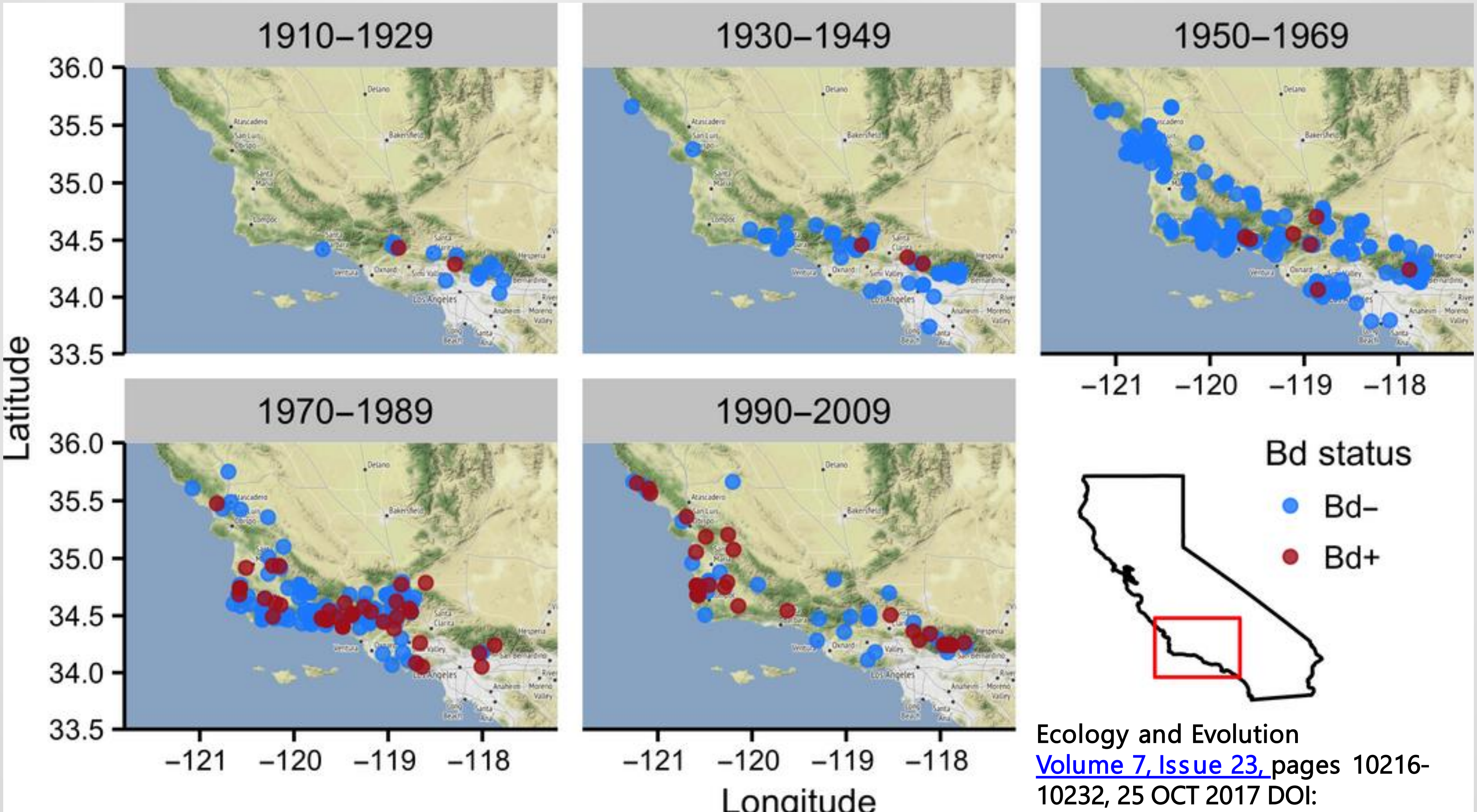
- Landscape features
- Dam attributes (size, distance, number)

Absent localities had:

- More dams upstream ($p<0.1$)
- Greater height of dams ($p<0.05$)

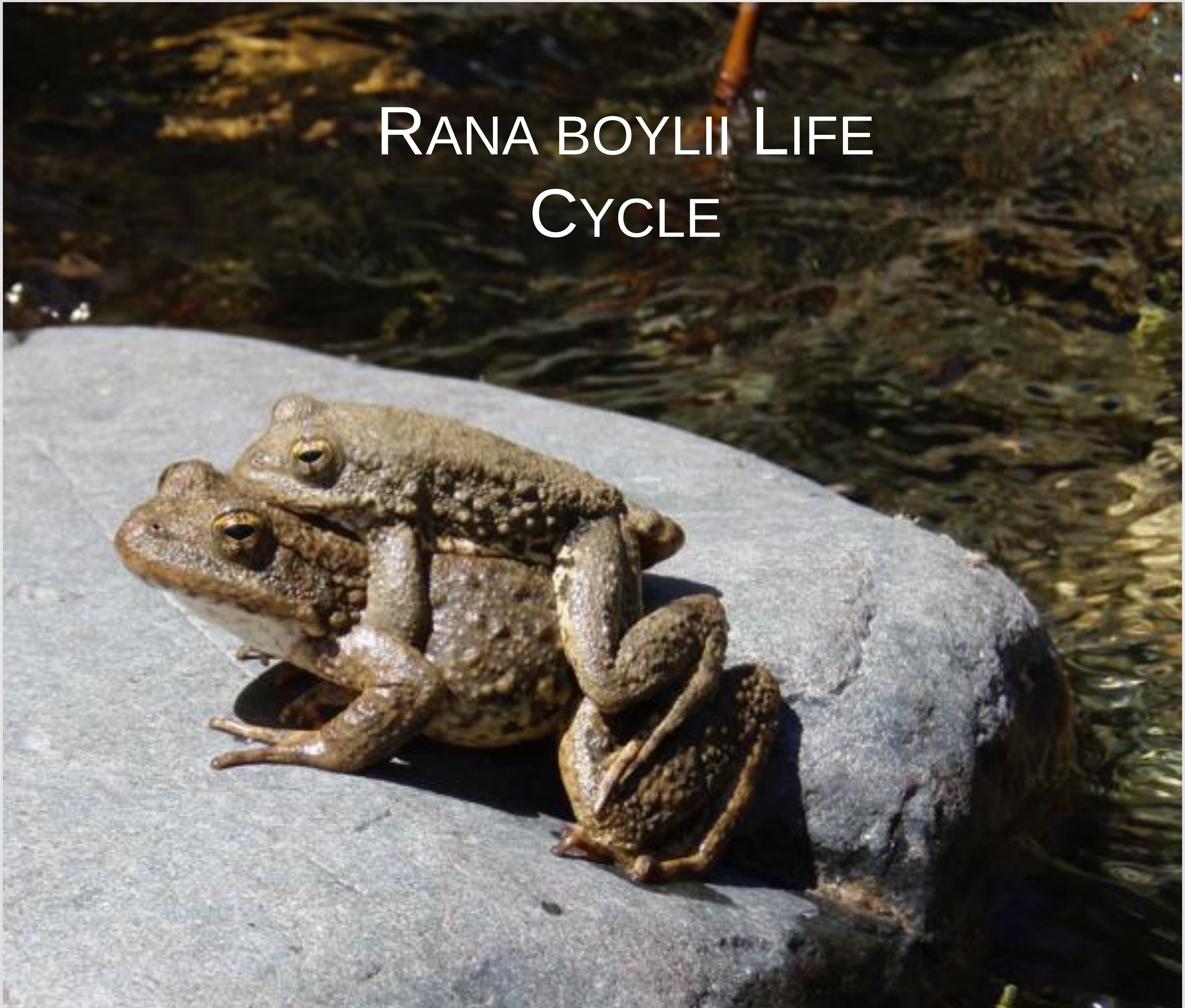
CHYTRID:

Extirpation in SoCal coincided w/ ↑ in fungal pathogen prevalence (*Andrea Adams 2017*)

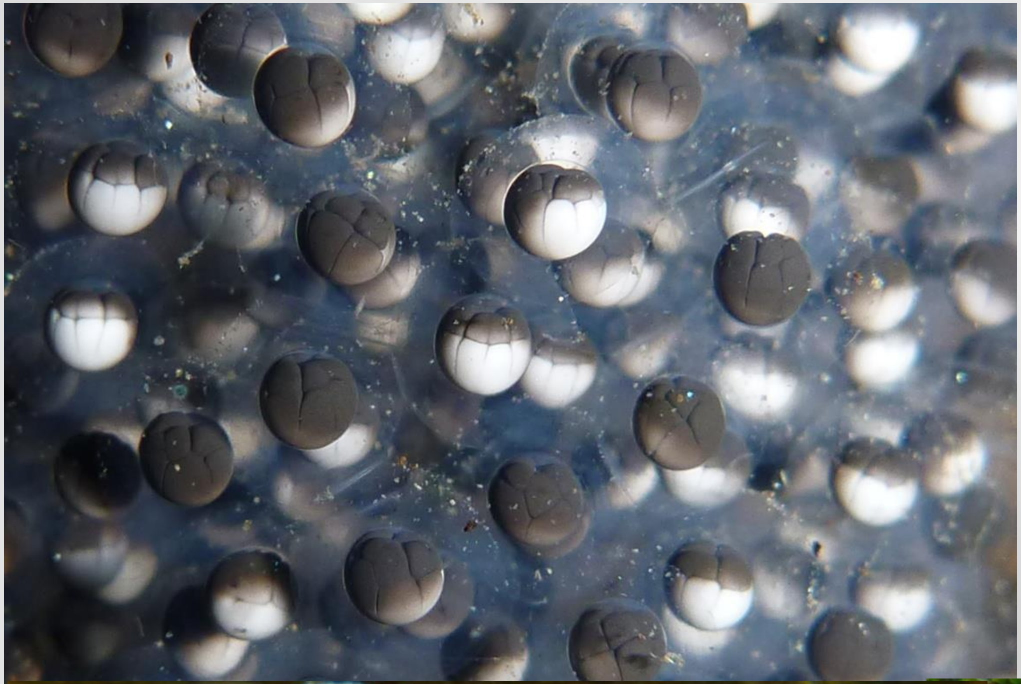


Ecology and Evolution
Volume 7, Issue 23, pages 10216-10232, 25 OCT 2017 DOI: 10.1002/ece3.3468

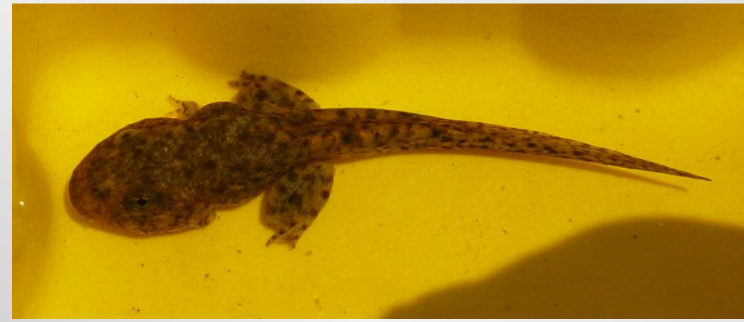
RANA BOYLII LIFE CYCLE



EGG MASSES



TADPOLES



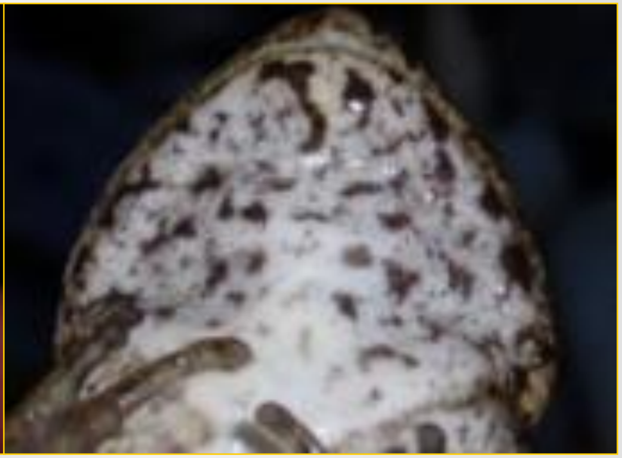
JUVENILES


ADULTS

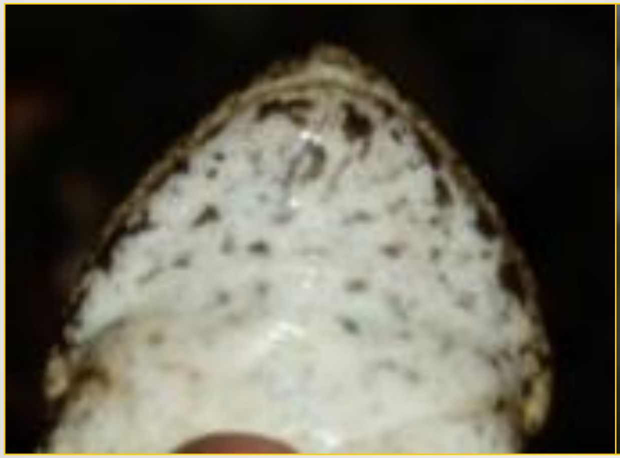
LONGEVITY: Recapture of a female in the NF Feather River indicates longevity can be ~12 years

Initial Capture 5/29/2004

3/1/2005



4/20/2007*



5/21/2008

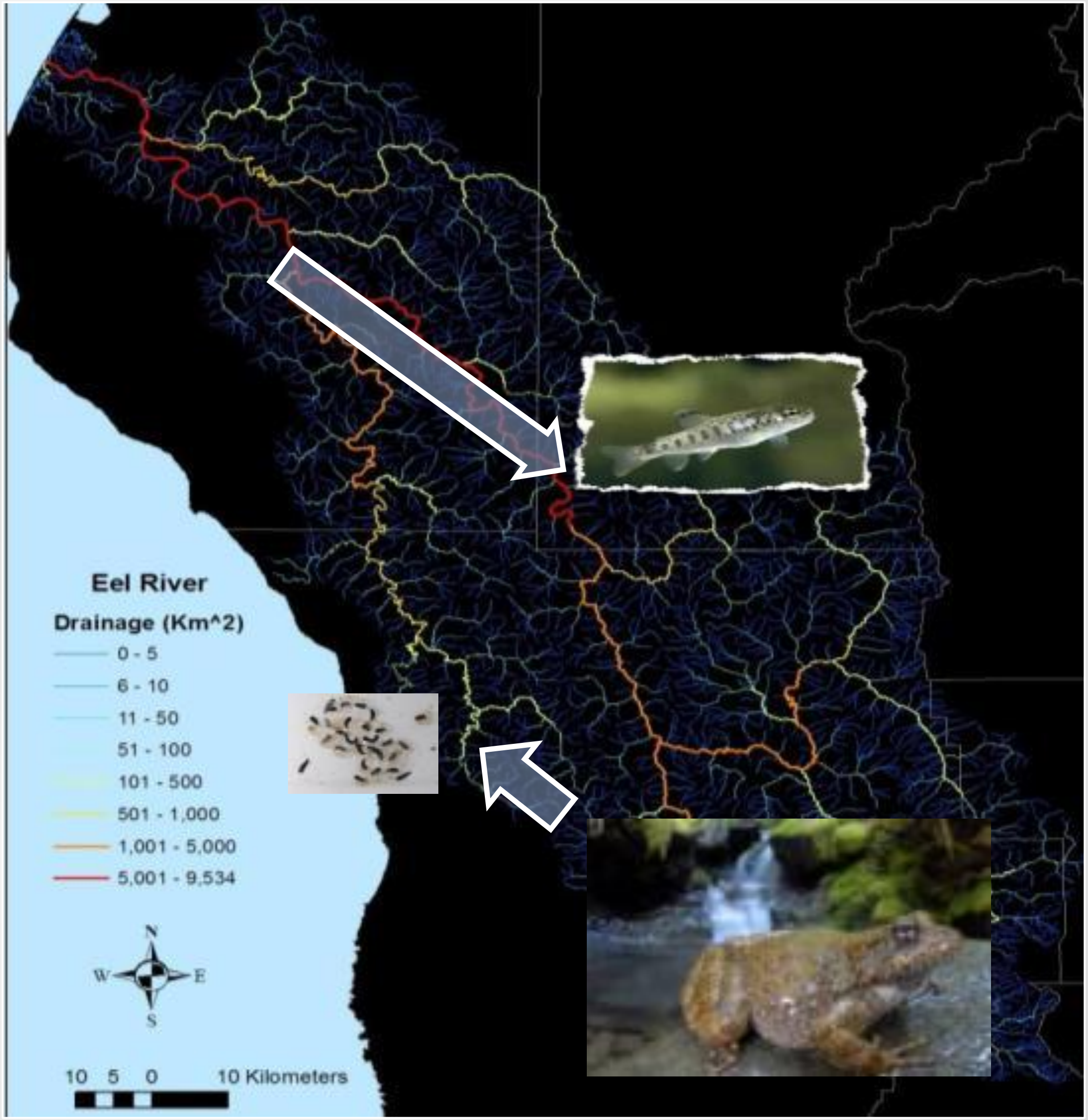
6/28/2009

5/10/2012

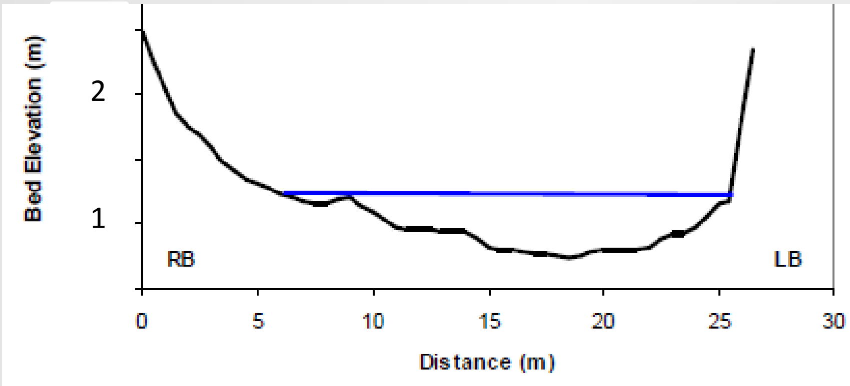
Spawning migrations

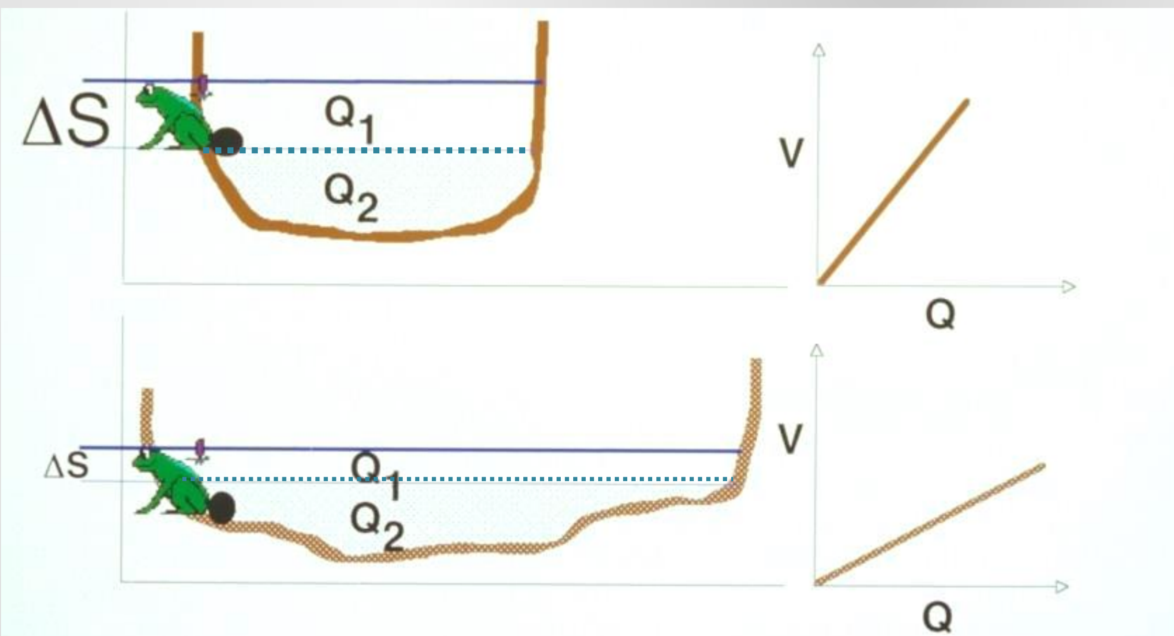
- Salmon, frogs move in opposite directions between trib. & mainstem habitats

- Max ≈ 7km

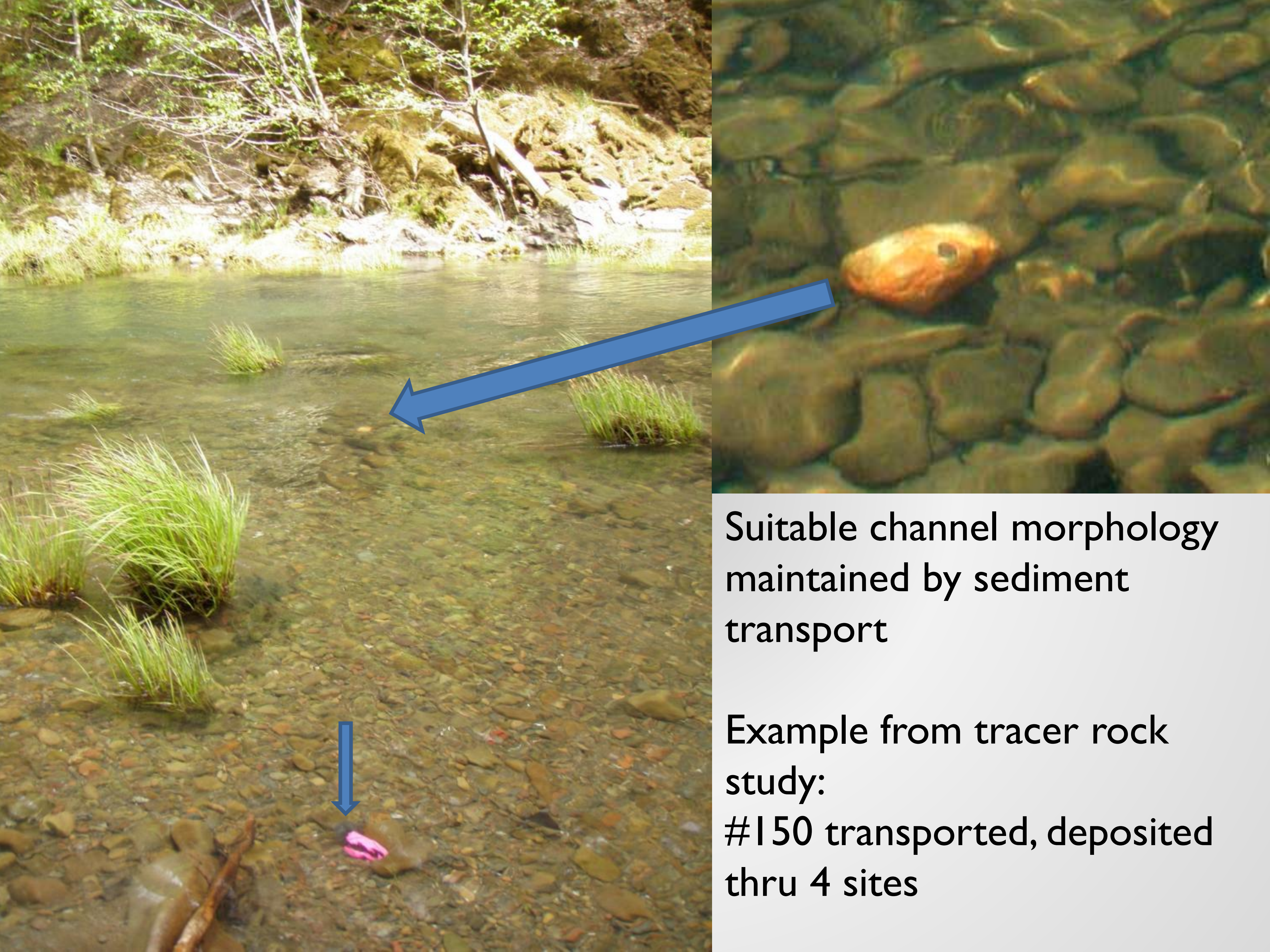


Breeding Habitat
Distinct Channel Morphology





- Fidelity to lek sites
- Same sites used year after year
- Often near tributary confluences
- Asymmetrical in bank slope
- Wide shape buffers changes in depth, and velocity

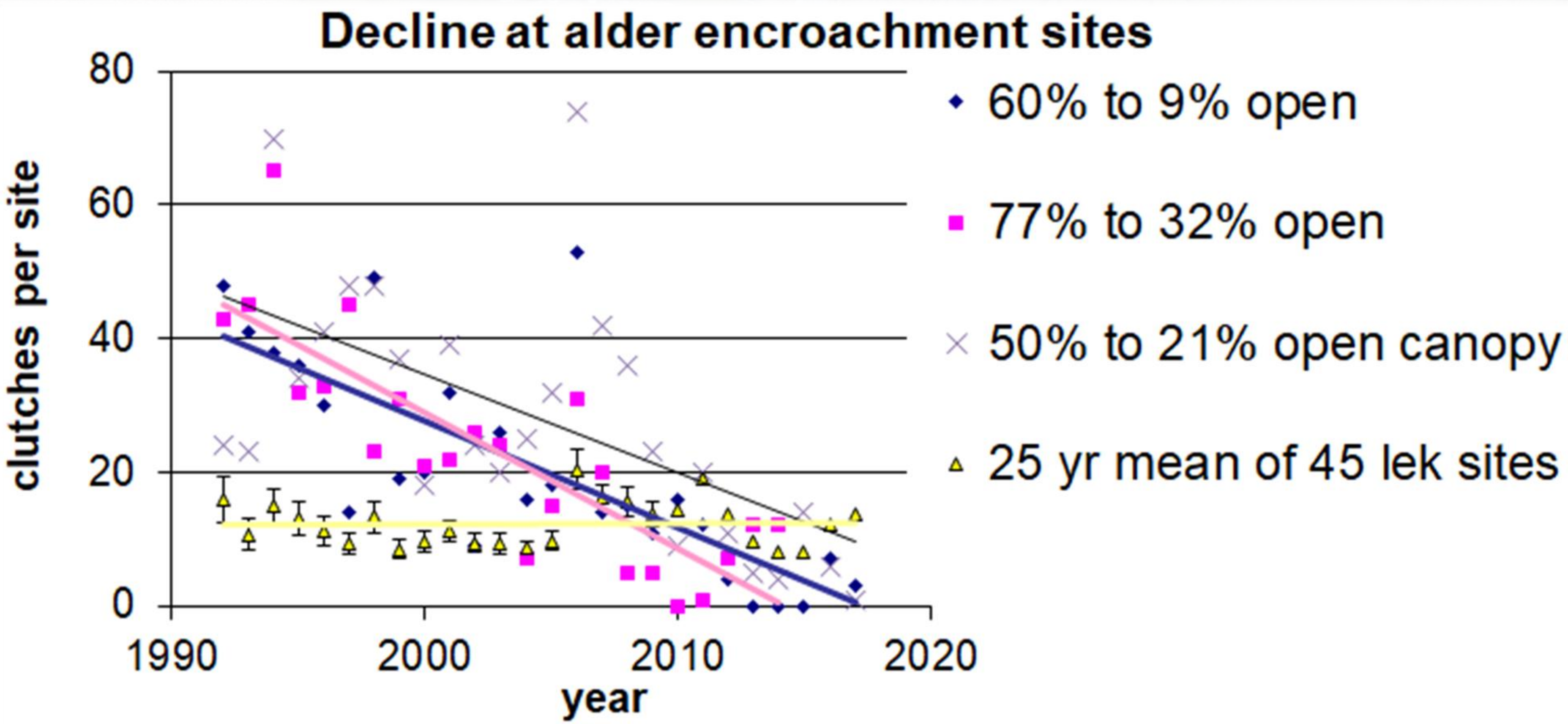


Suitable channel morphology maintained by sediment transport

Example from tracer rock study:
#150 transported, deposited thru 4 sites

Natural disturbance regime vs. suppressed by dam


Natural disturbance regime vs. suppressed by dam



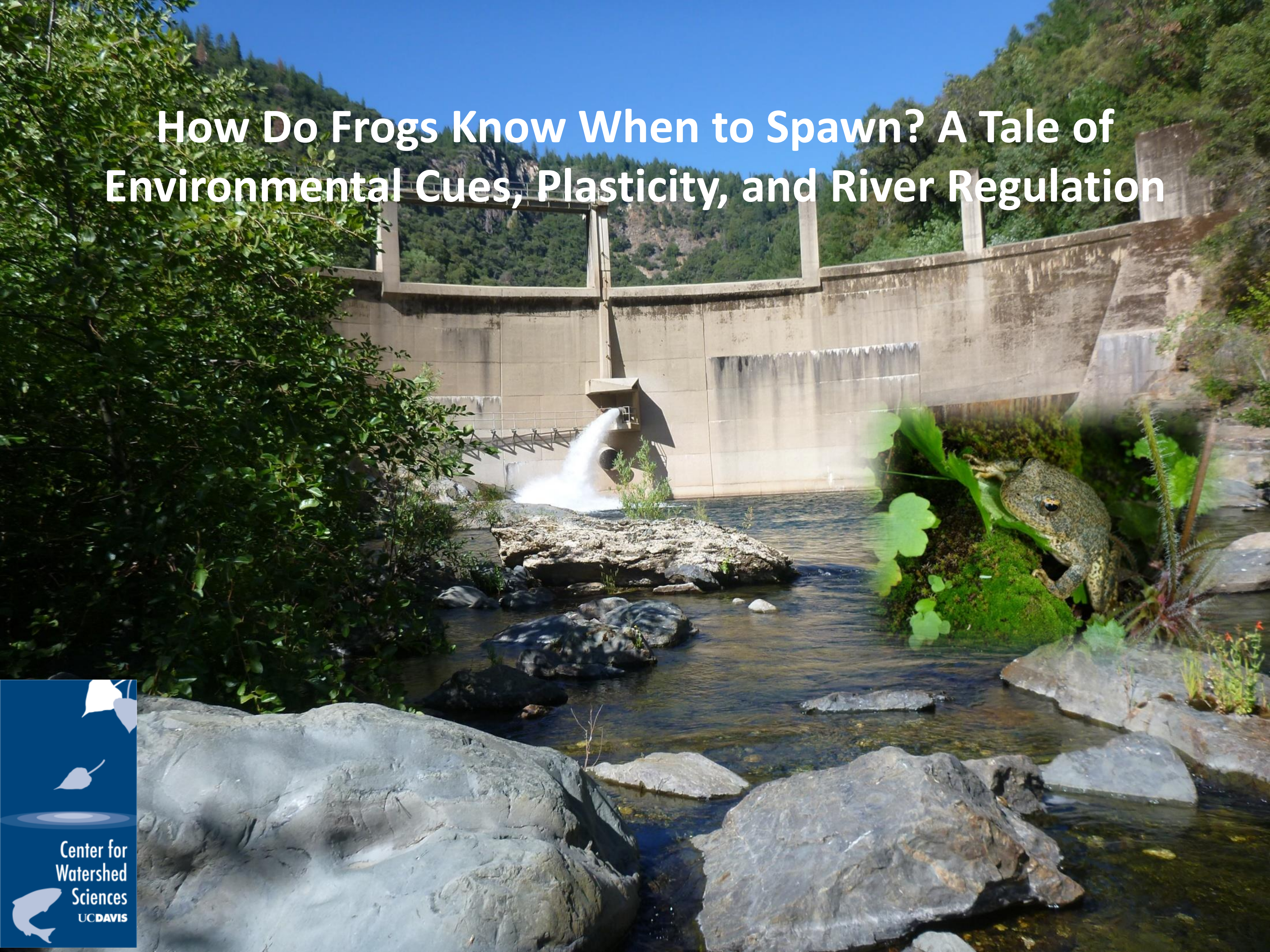
Relevance for permitting

How will a project affect channel, sediment transport?

Rana boylii

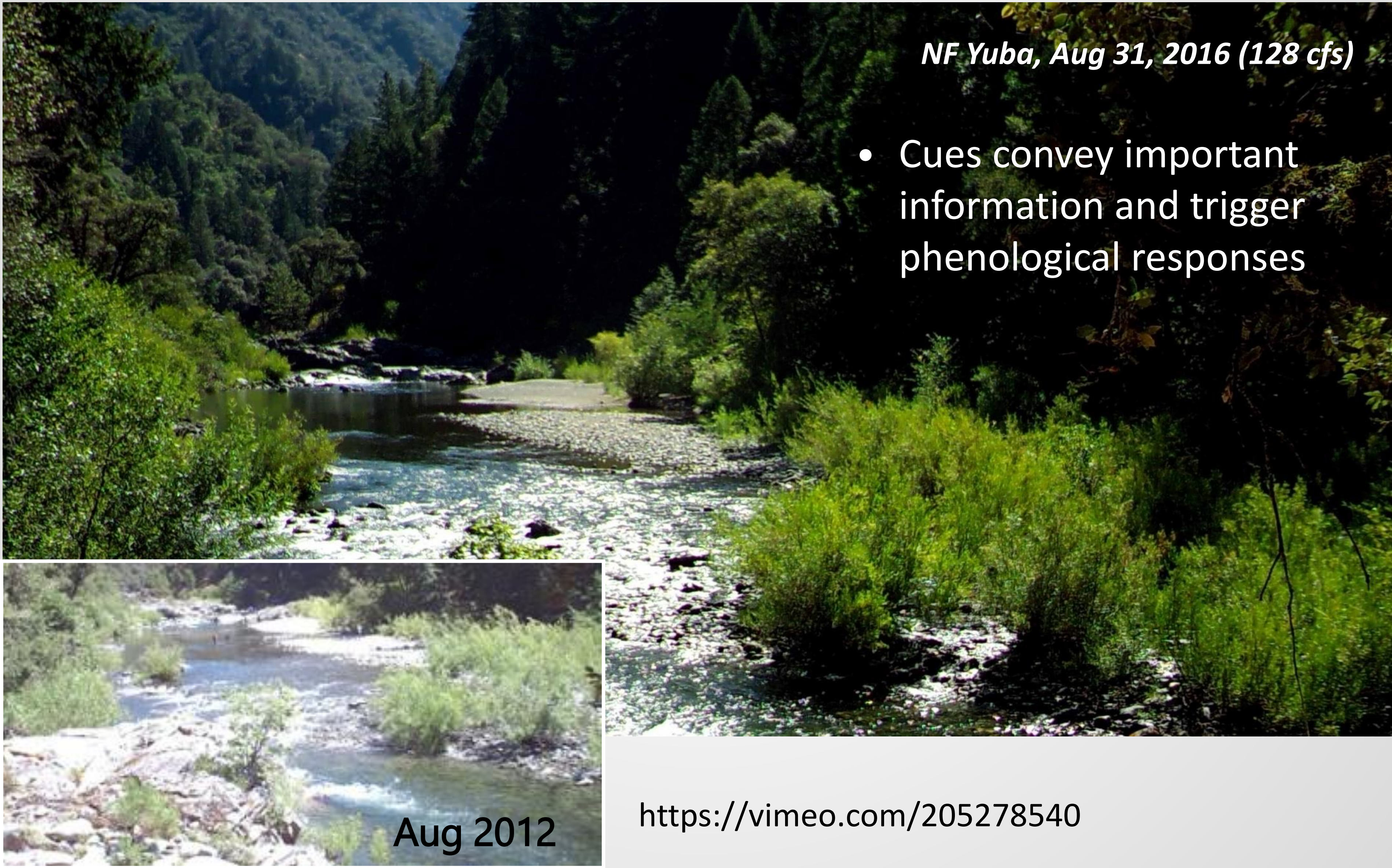
- Natural History
- **Breeding Timing & Plasticity**
- Ecology
- Conservation Genetics
- Population Dynamics

How Do Frogs Know When to Spawn? A Tale of Environmental Cues, Plasticity, and River Regulation



Center for Watershed Sciences
UC DAVIS

Environmental Cues in Mediterranean River Ecosystems



https://vimeo.com/205278540

Environmental Cues in Mediterranean River Ecosystems

- Reliable cues have seasonal predictability (consistency)

Aug 2012

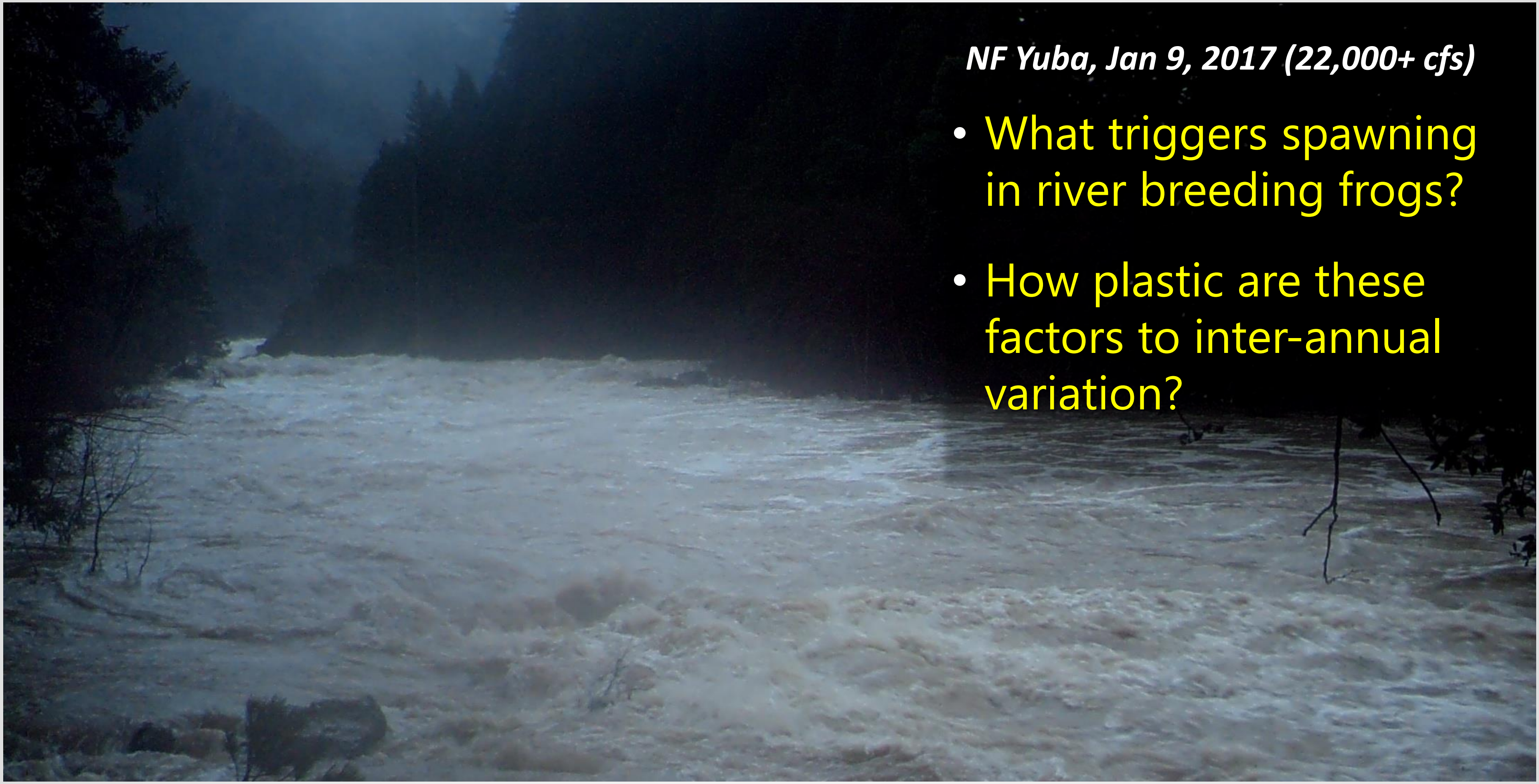
https://vimeo.com/205278540

Environmental Cues in Mediterranean River Ecosystems

- Global climate change has been implicated in phenological shifts for a variety of taxa

https://vimeo.com/205278540

Environmental Cues in Mediterranean River Ecosystems



NF Yuba, Jan 9, 2017 (22,000+ cfs)

- What triggers spawning in river breeding frogs?
- How plastic are these factors to inter-annual variation?

https://vimeo.com/205278540

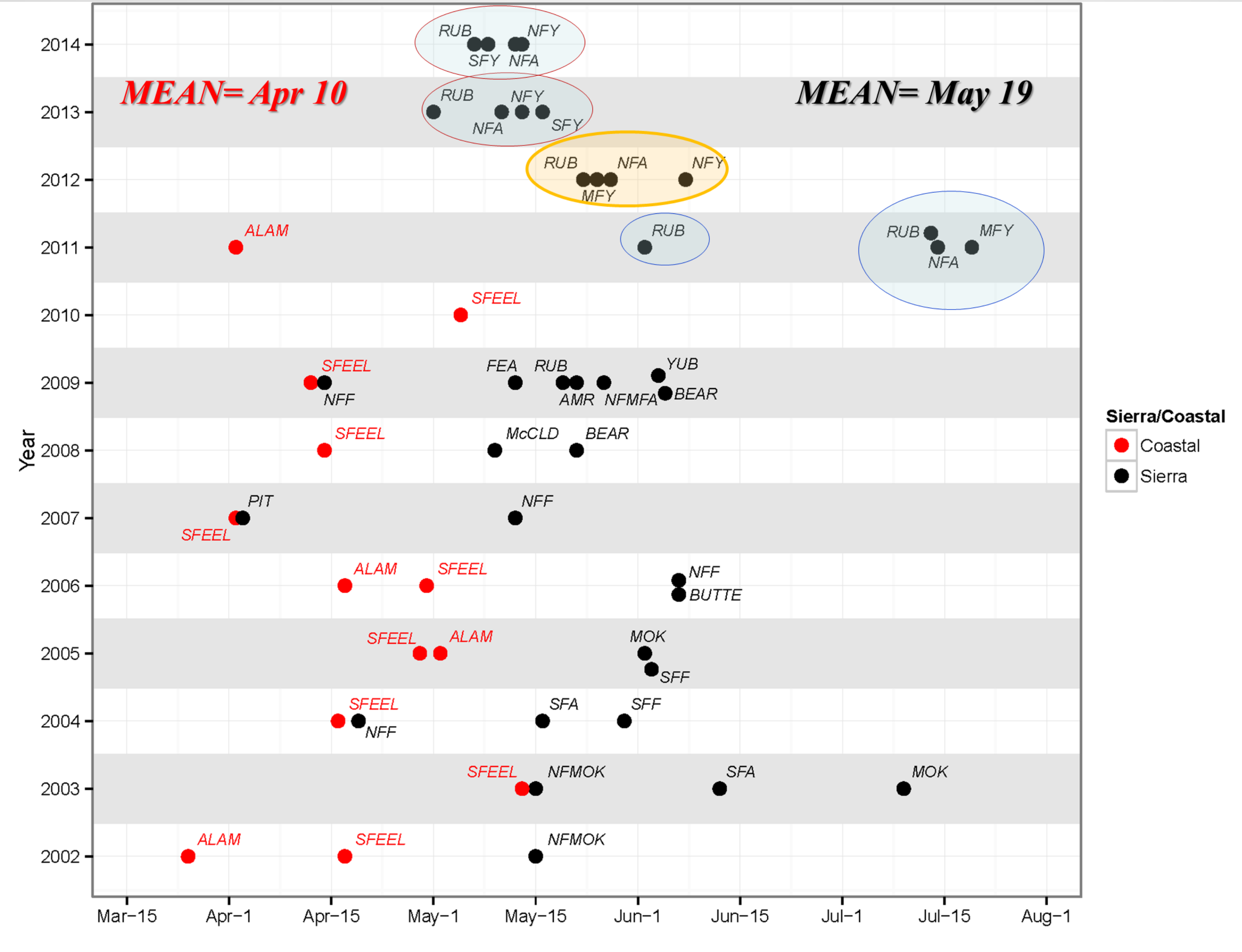
Rana boylii: *Hydrology & Breeding Habitat*

- Strongly linked with temporal and regional hydrology
- Oviposition is strongly tied to local cues of receding flow rate and increasing water temperature
- Breeding phenotypes?

- **90% of eggs observed in Sierras were in shallow, sheltered waters (n=147)**
  - **< 0.67 m total depth**
  - **< 0.15 m/s velocity**

Bondi et al. 2013

Breeding Timing: Coastal vs. Sierra Phenotypes?

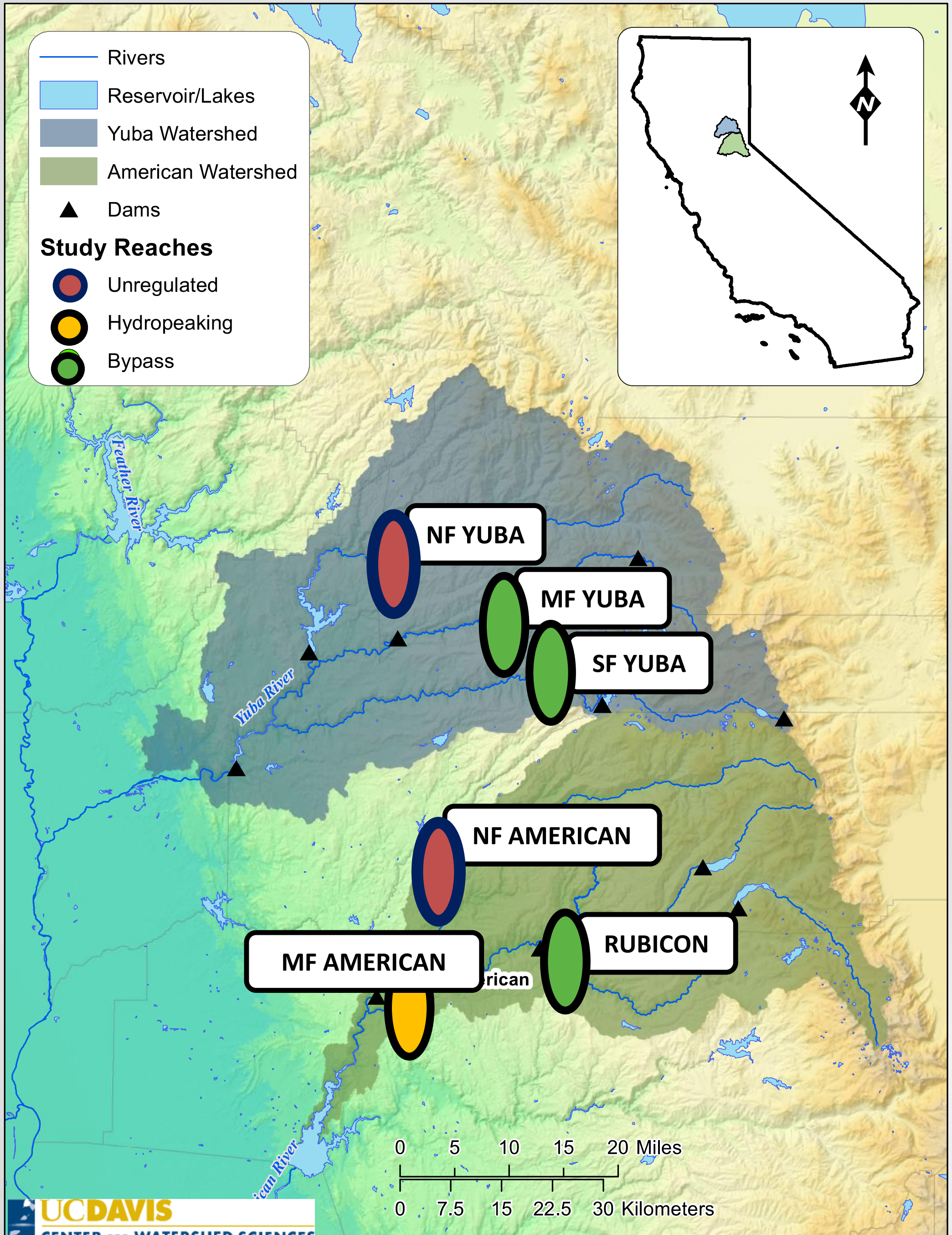


Breeding Timing Questions

- What hydroclimatic cues best explain initiation of frog oviposition (spawning)?
- How might river regulation impact the "plasticity" of these cues?

METHODS:

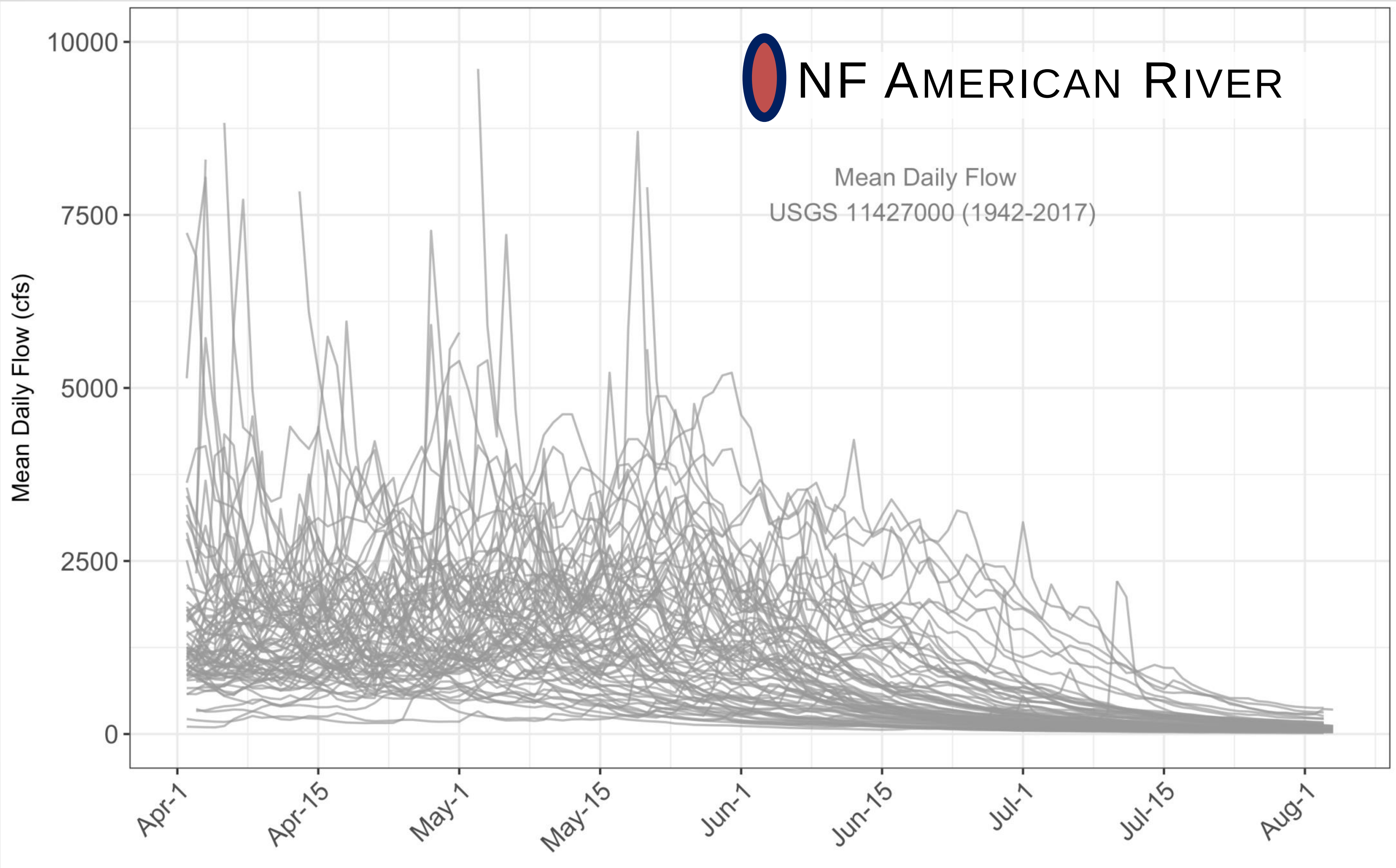
- Egg Mass surveys
- Modeling: which variables strongest predictors of frog spawn timing?
- Use index used to measure seasonality/predictability of flow patterns between regulated / unregulated sites (*see Tonkin et al. 2017*)



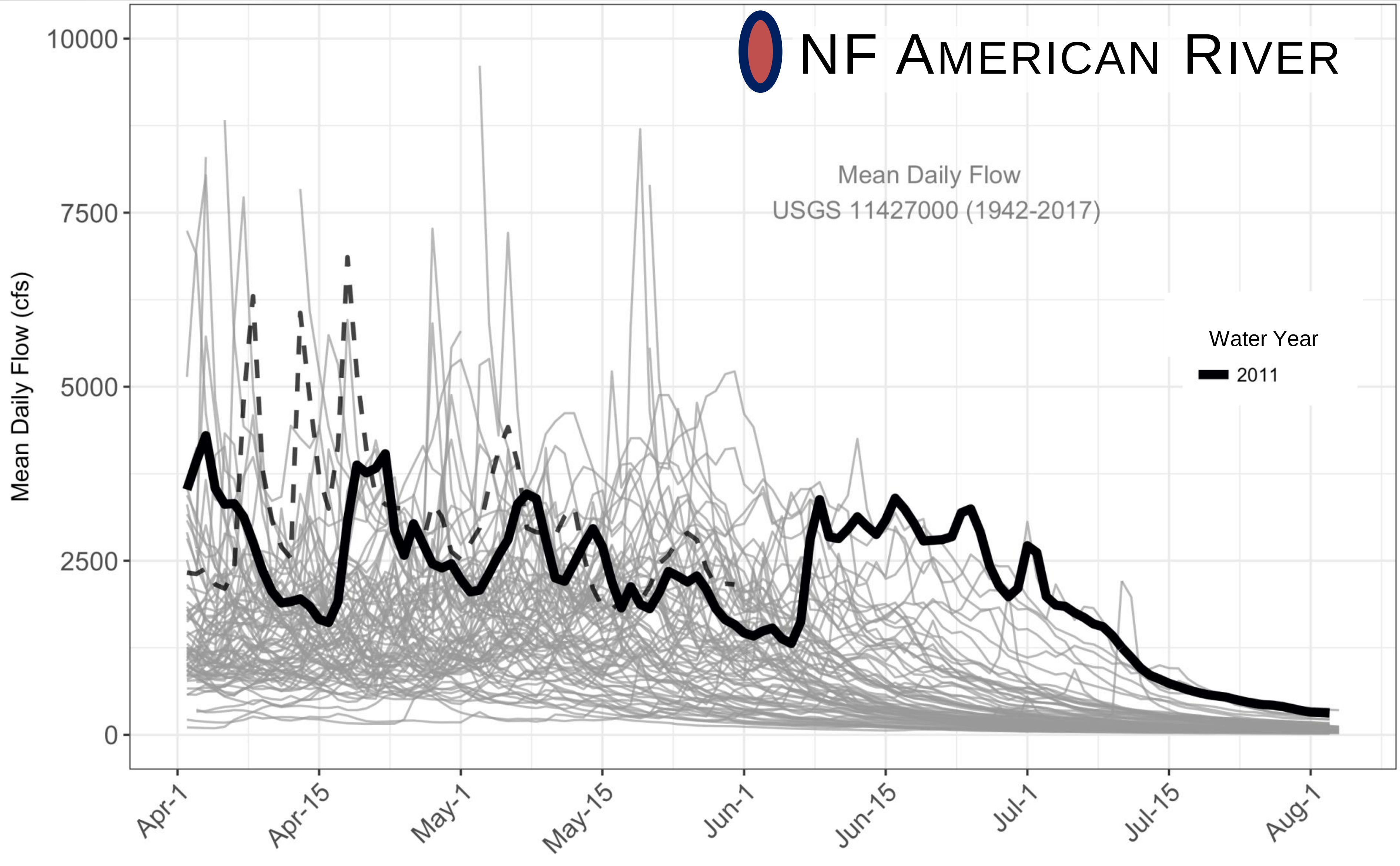
Study Sites

- Paired watersheds
- Different regulated flow regimes (**unregulated**, **hydropeaking**, **bypass**)
- Assessed 25 different variables relating to flow, water/air temperature, & precipitation
- Data from CDEC & USGS gages data and field loggers

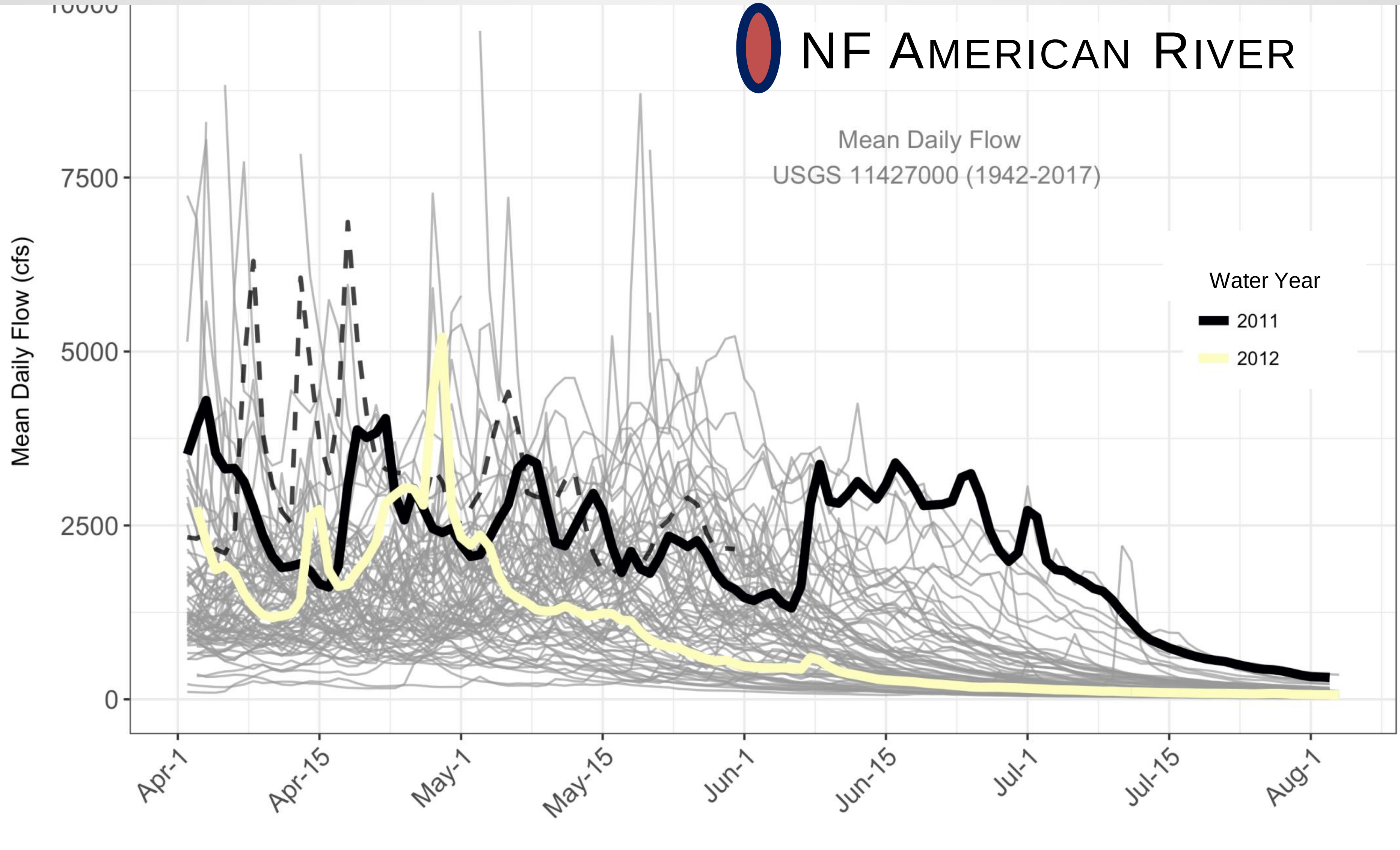
Hydrologic Variation & Extremes: Unregulated Flow



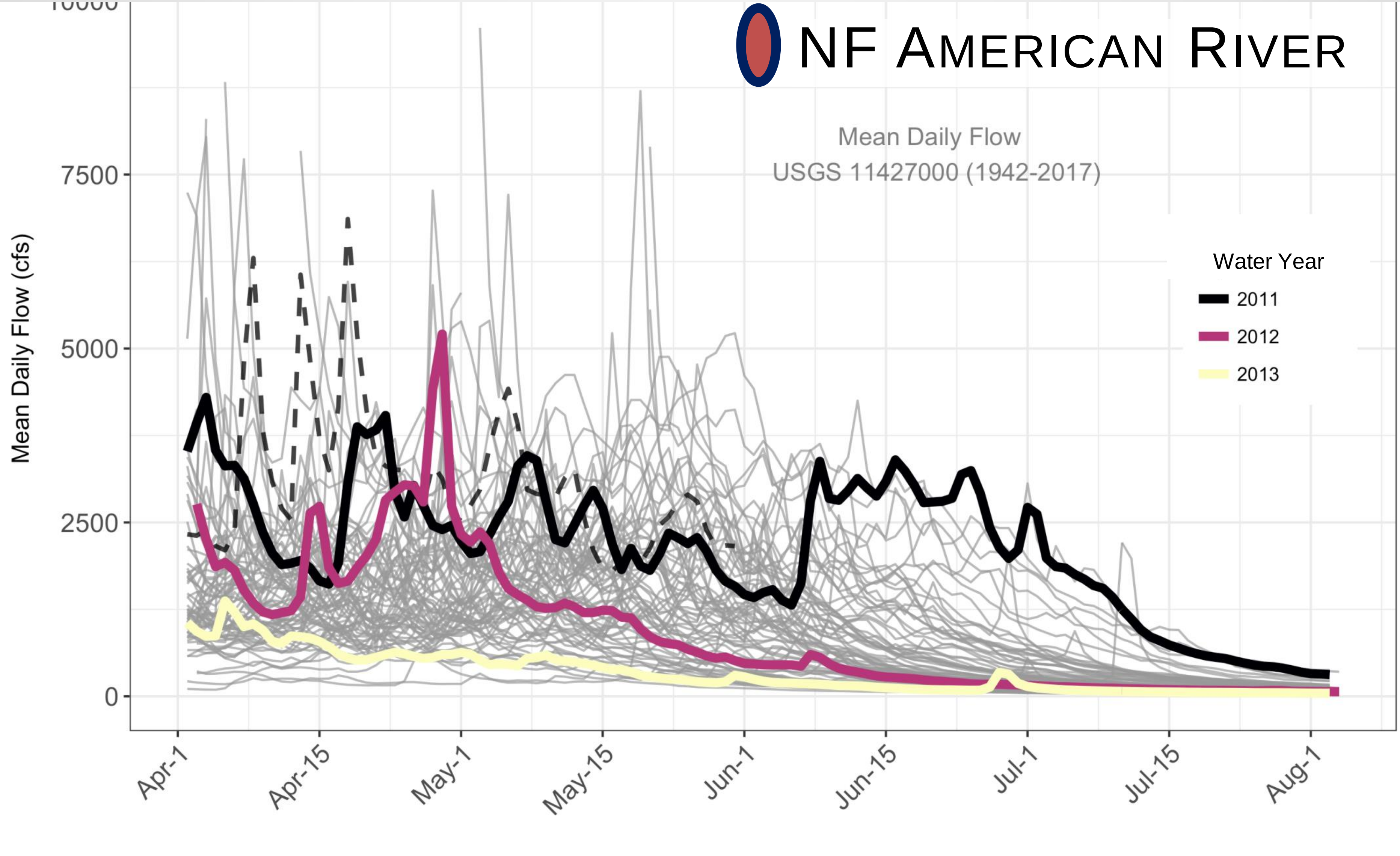
Hydrologic Variation & Extremes: Unregulated Flow



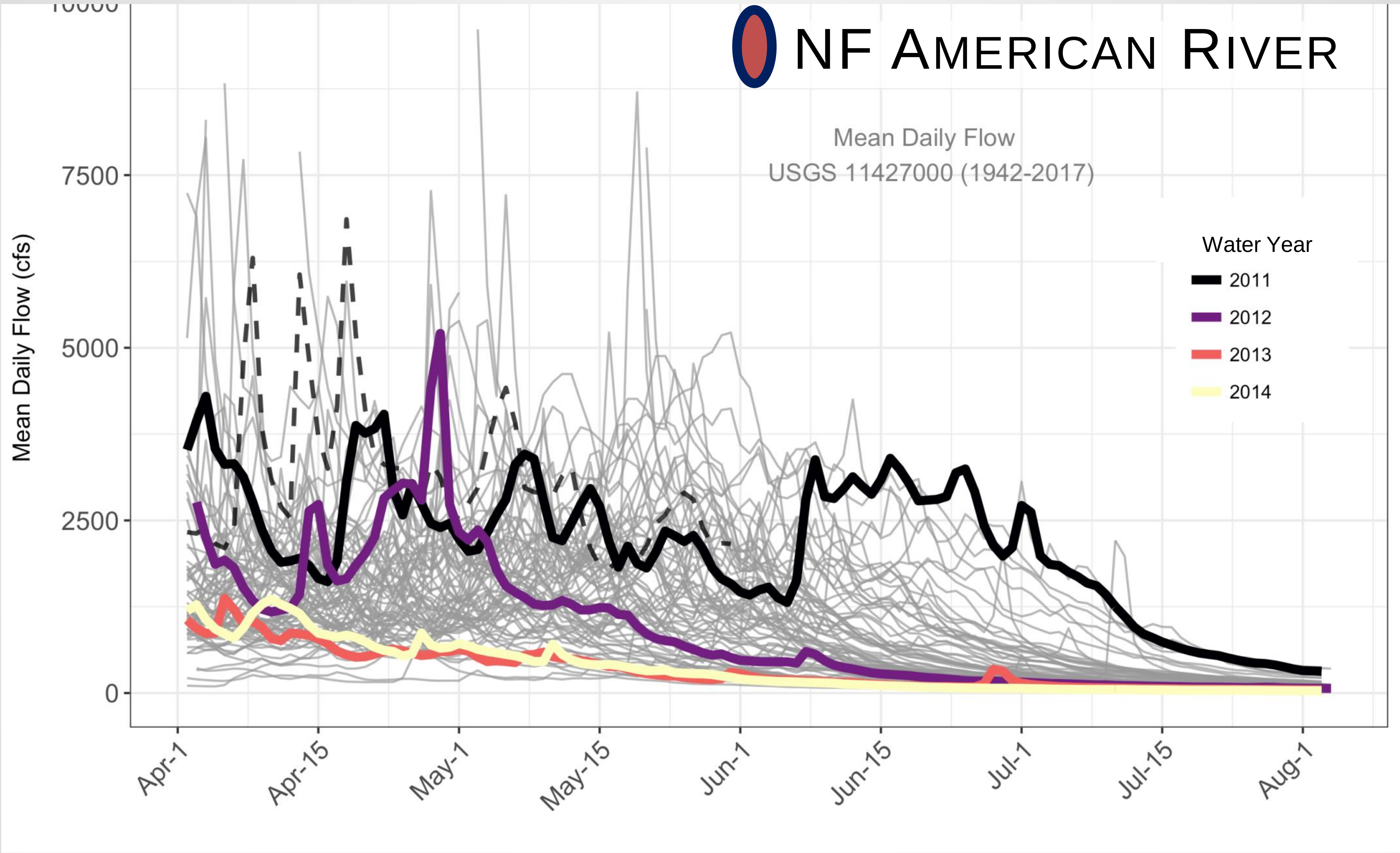
Hydrologic Variation & Extremes: Unregulated Flow



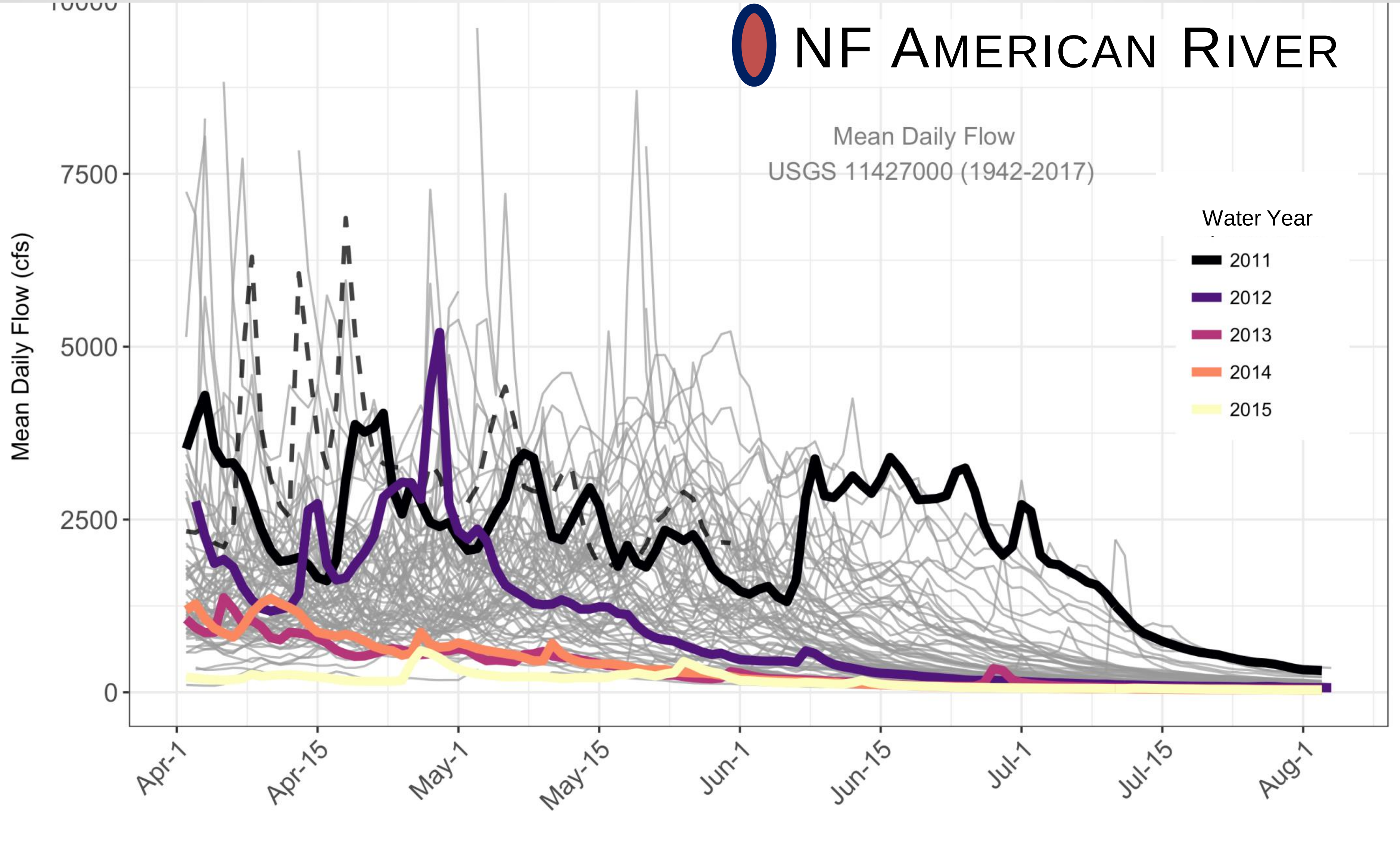
Hydrologic Variation & Extremes: Unregulated Flow



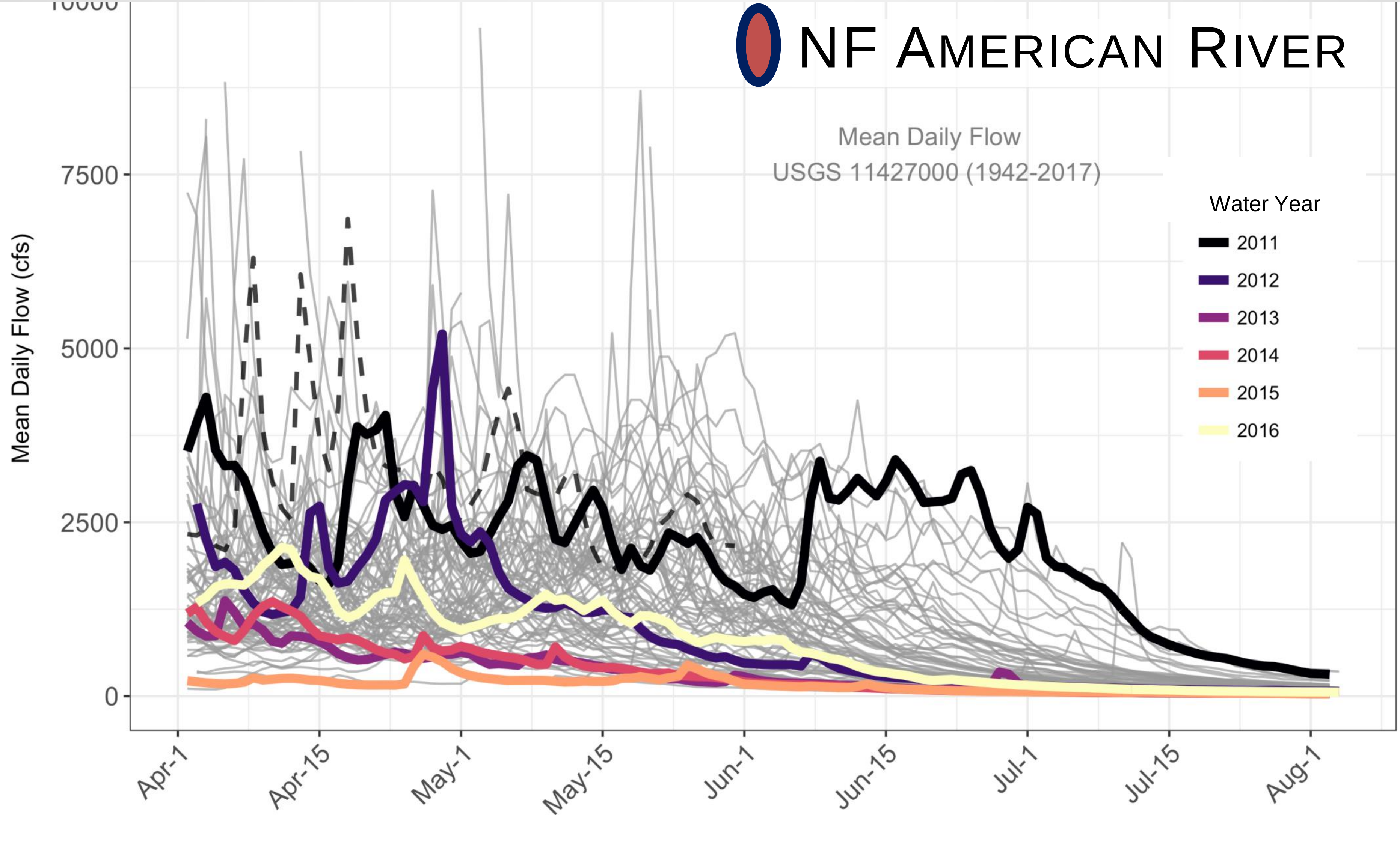
Hydrologic Variation & Extremes: Unregulated Flow



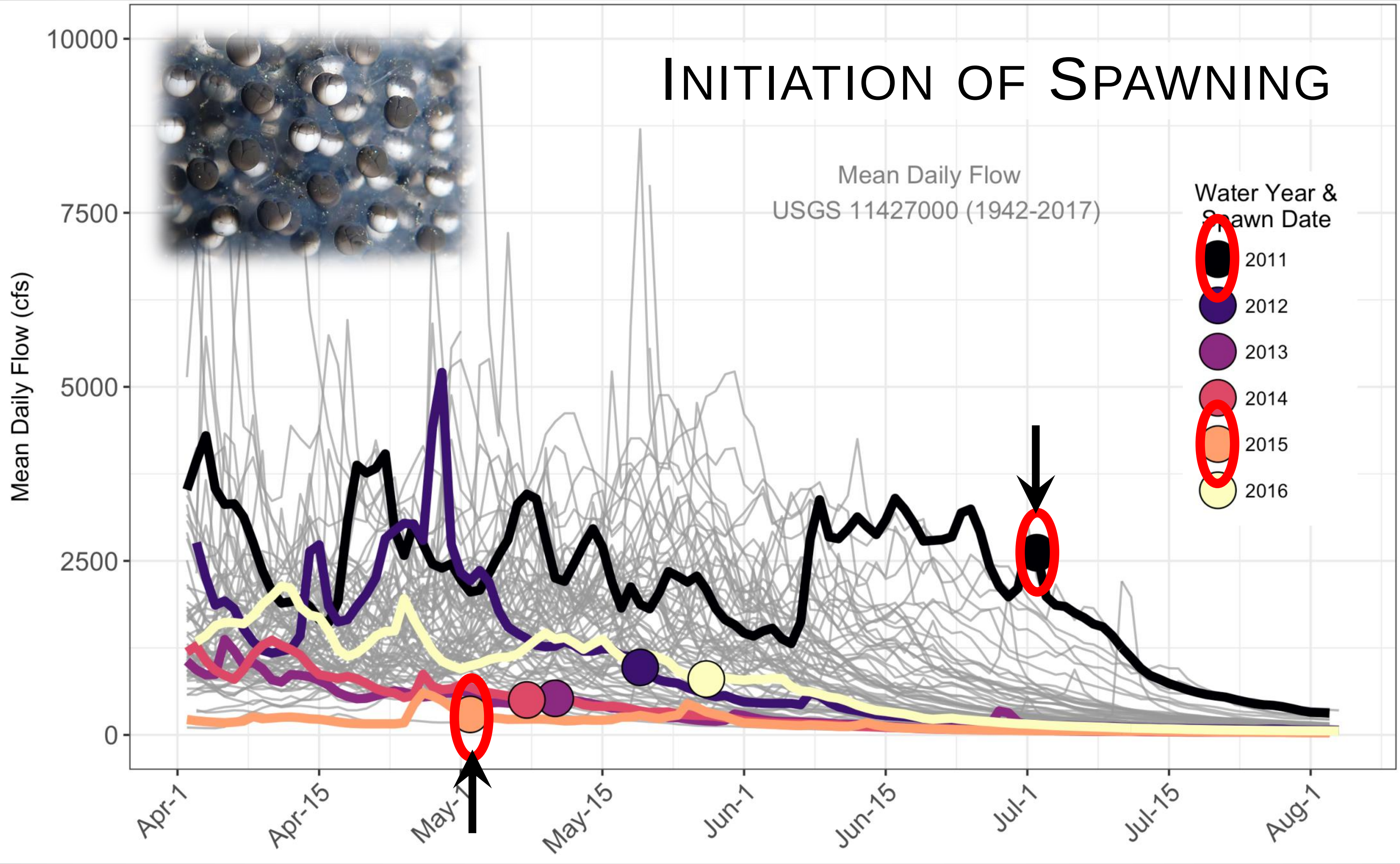
Hydrologic Variation & Extremes: Unregulated Flow



Hydrologic Variation & Extremes: Unregulated Flow



Spawning Plasticity: Unregulated Flow



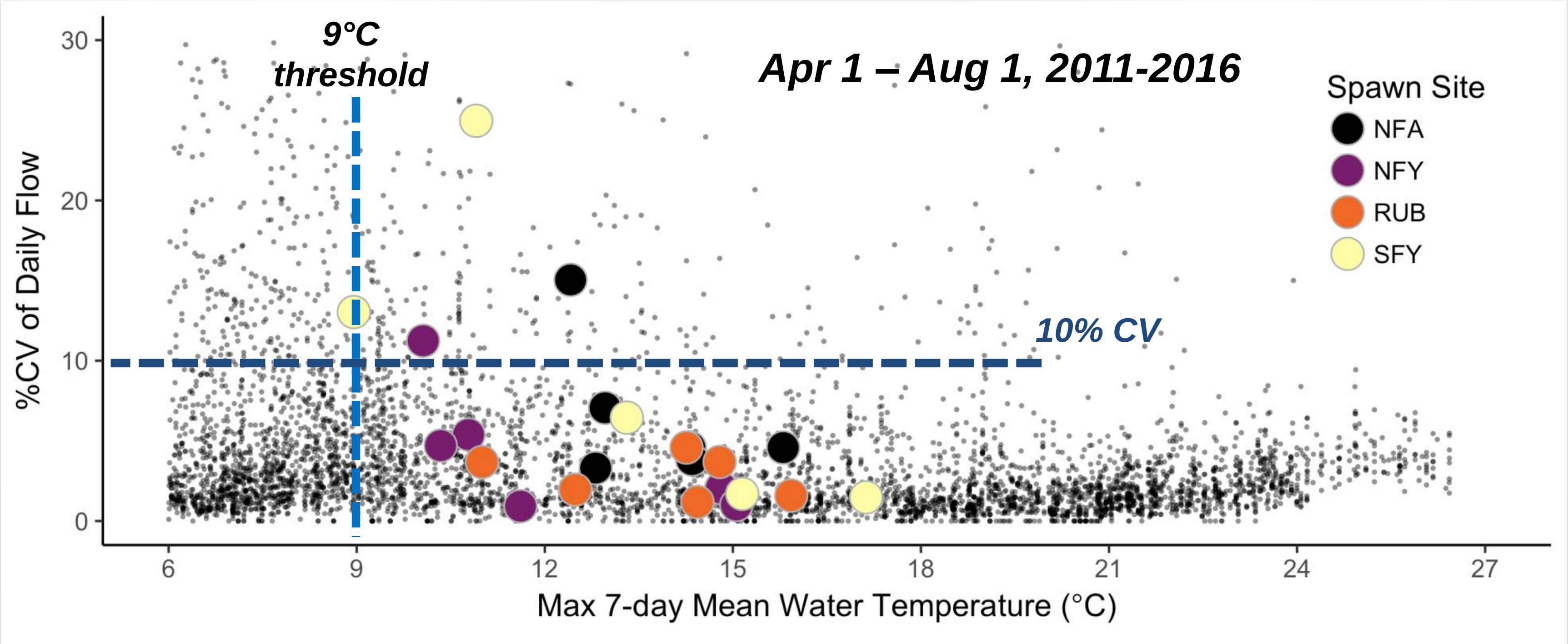
Multivariate Modeling Spawning Cues

How?

- Bayesian multi-level GLMs
- Used R 3.4.0 with `rethinking` package and STAN (MCMC),

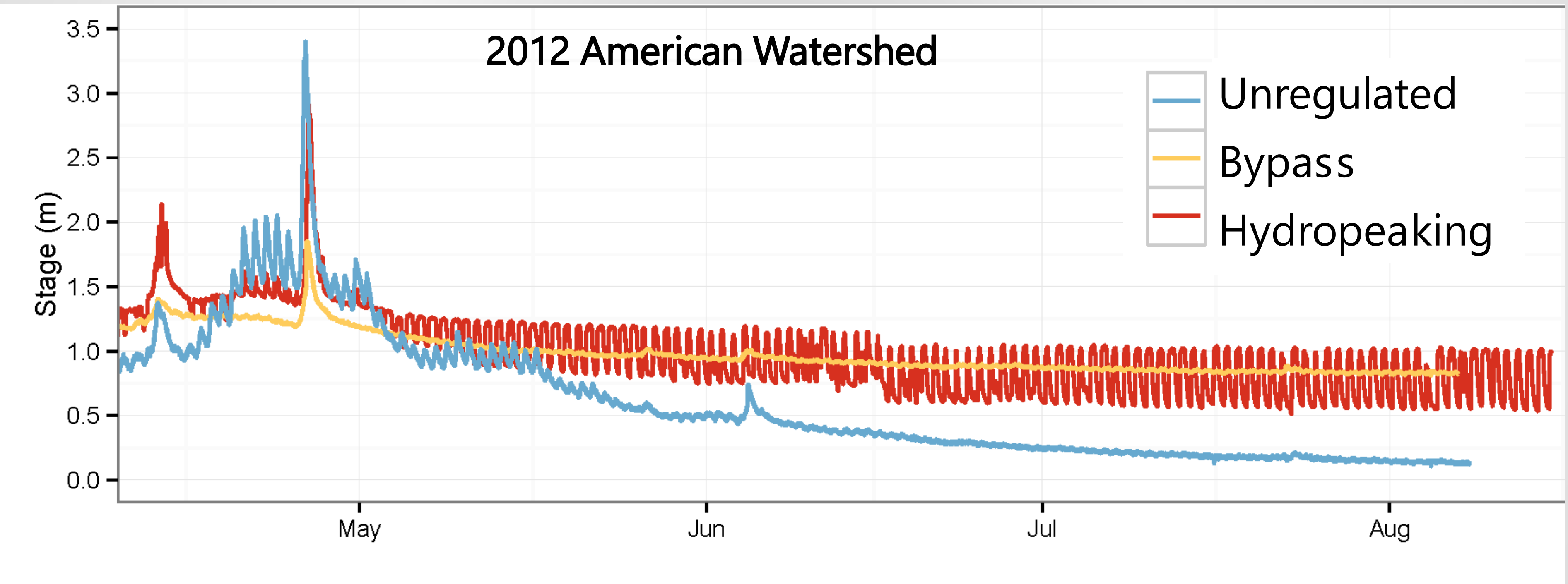
Results: Strongest predictors

- **Max 7-day Mean Water Temp.**
- **CV of daily Flow**
- **Regulation (binary)**
- **Water Year**

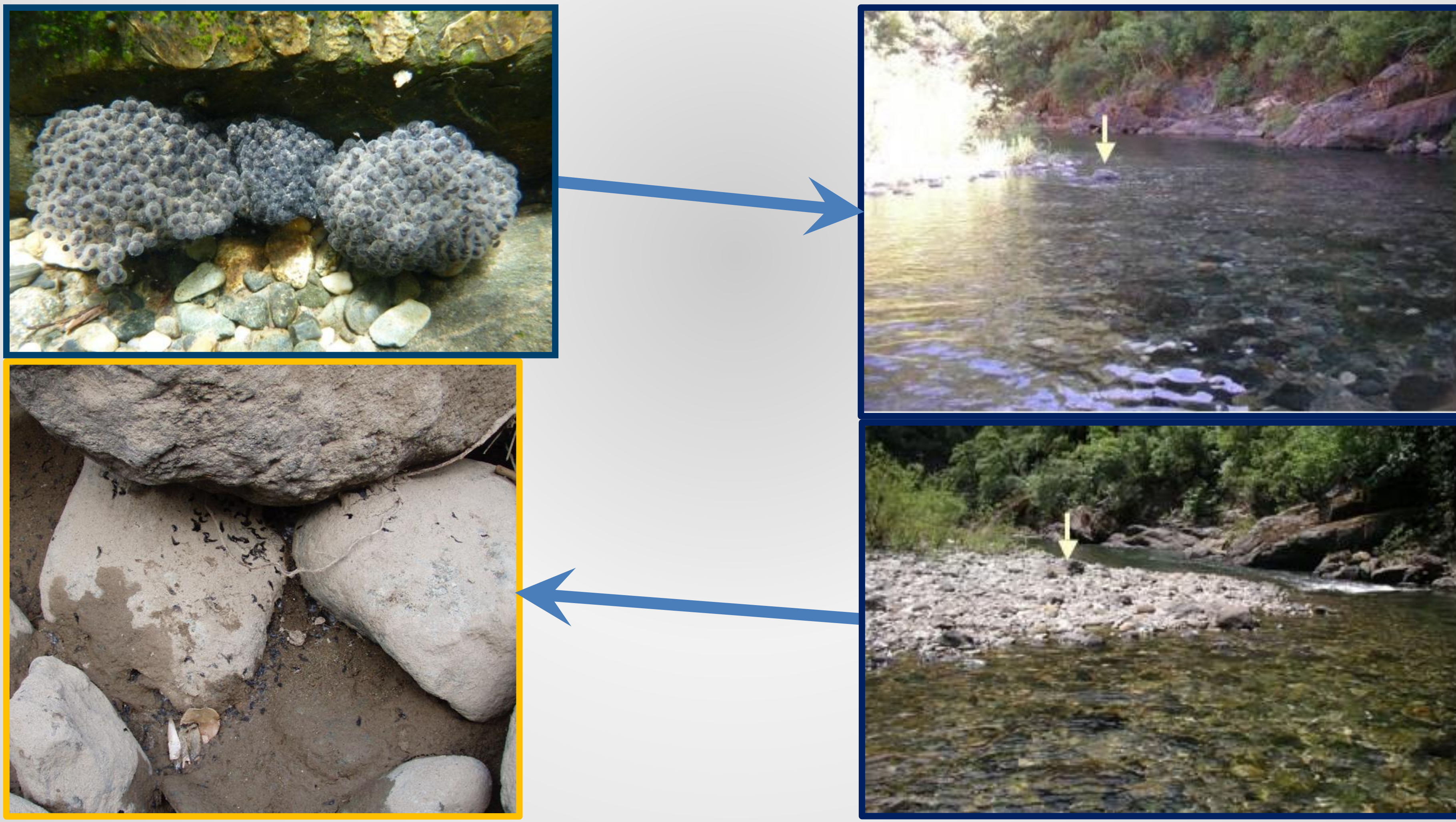


RIVER HYDROLOGY

- Regulation changes river flow regime *Timing, Frequency, Magnitude, Predictability, Rate of Change, Duration*



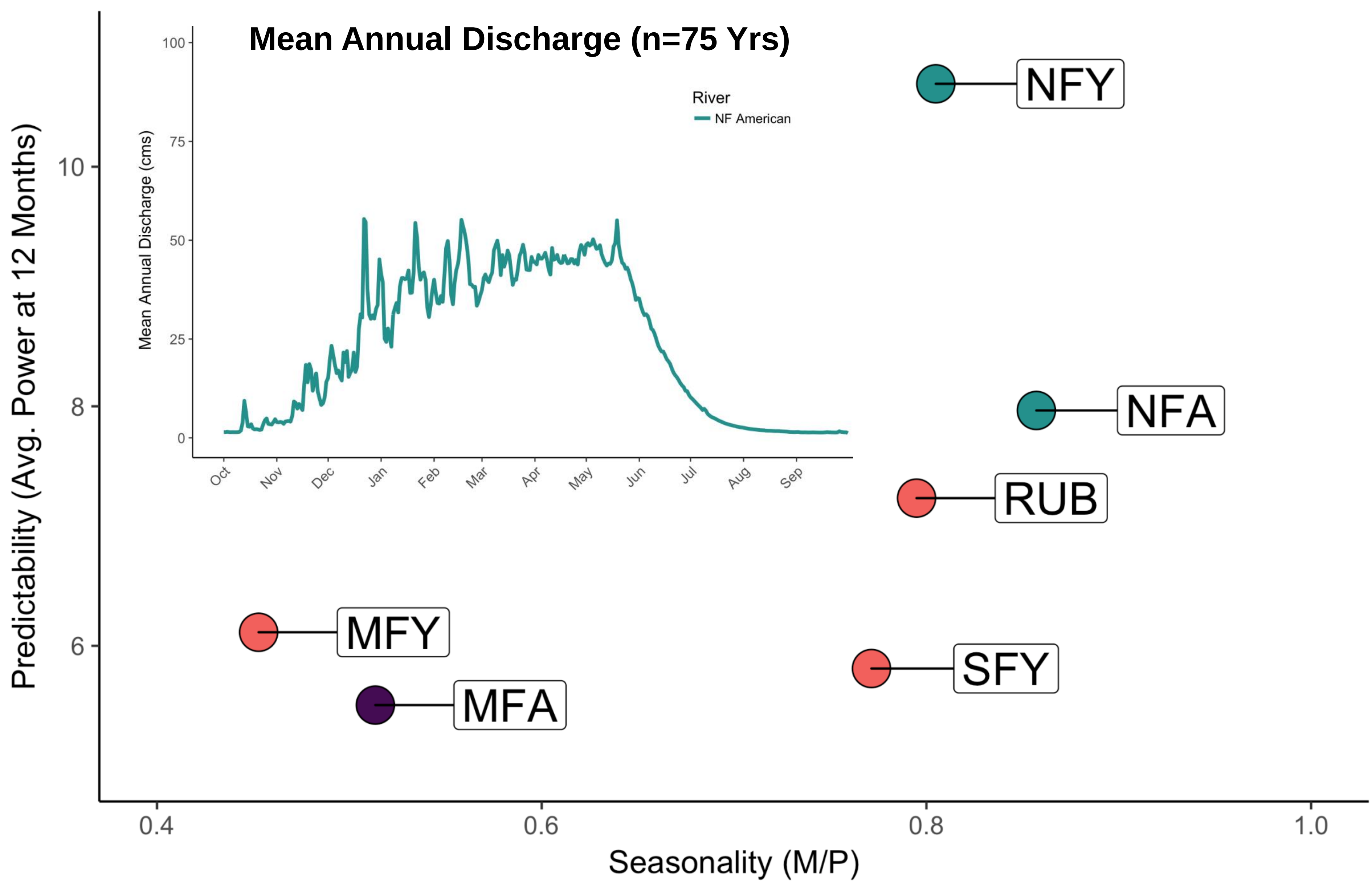
Impacts of Flow Regulation on Breeding (Eggs)



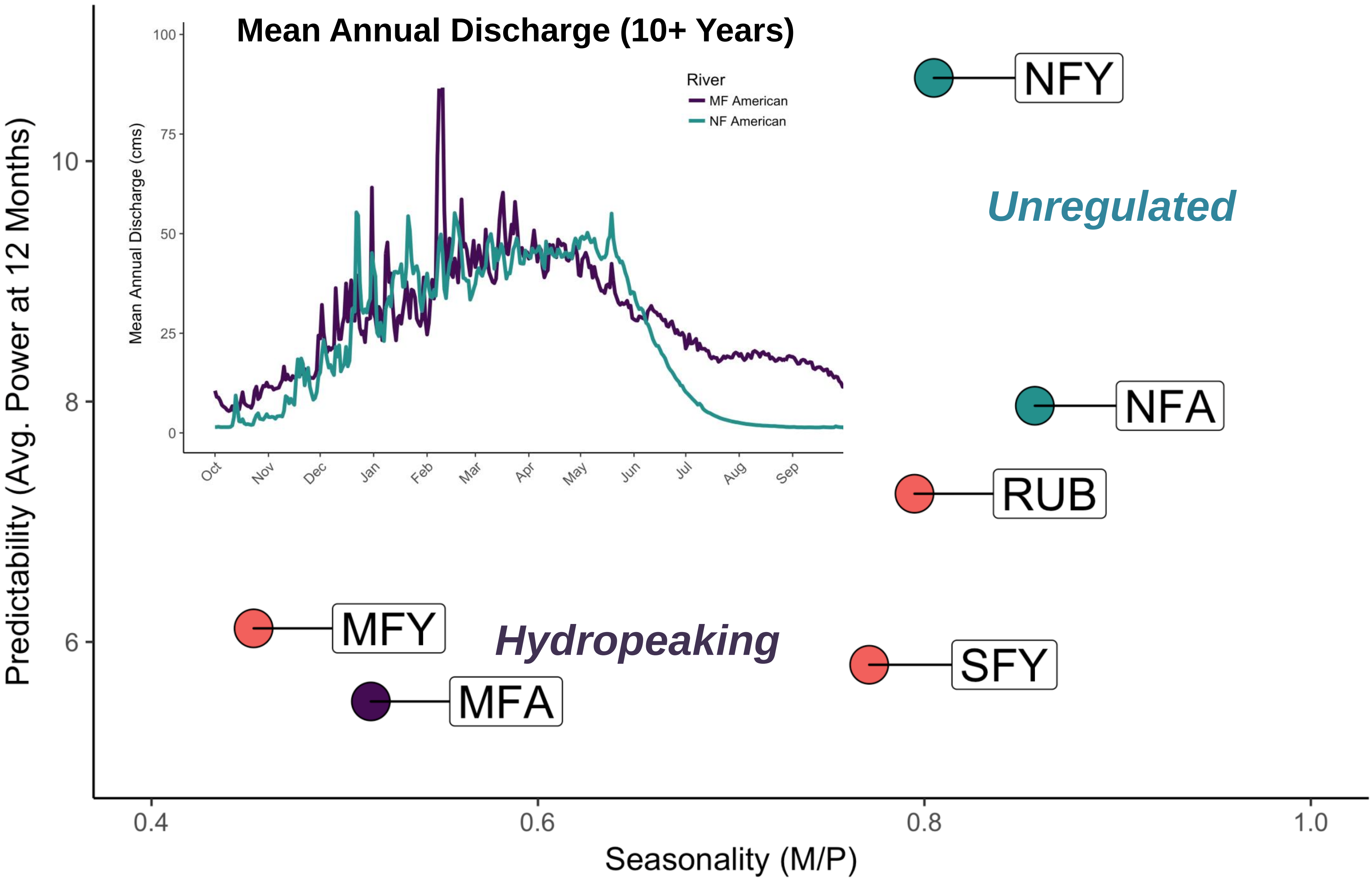
PREDICTABILITY VS SEASONALITY

- **Seasonality** is measure of occurrence of distinct within-year conditions or events
- **Predictability** is the regularity of recurrence annually
- Assessed 10+ years of flow data using *Colwell's M/P* index and *Wavelet* analysis following **Tonkin et al. 2017, (see Box 1 in paper**)

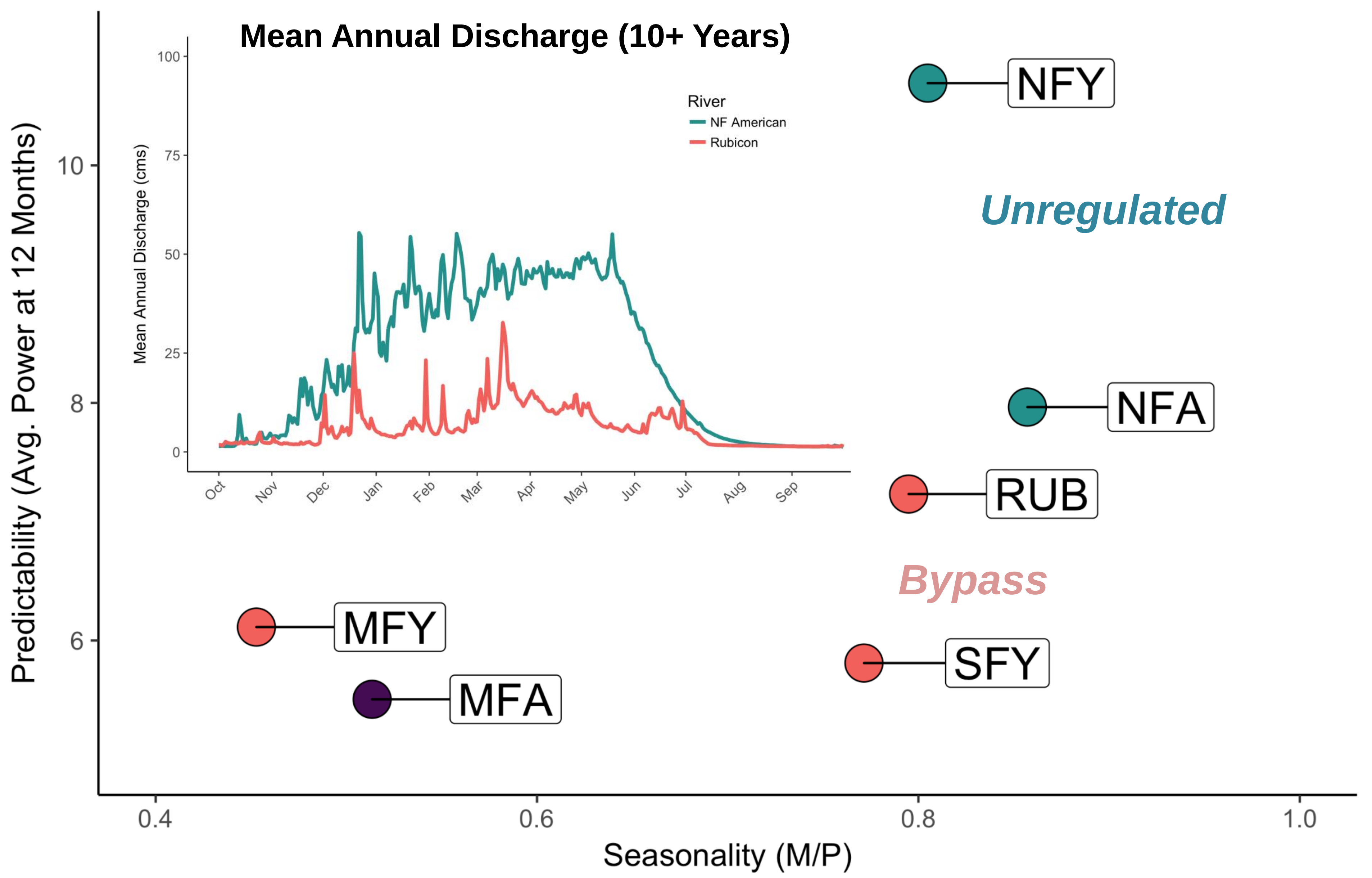
Predictability vs Seasonality



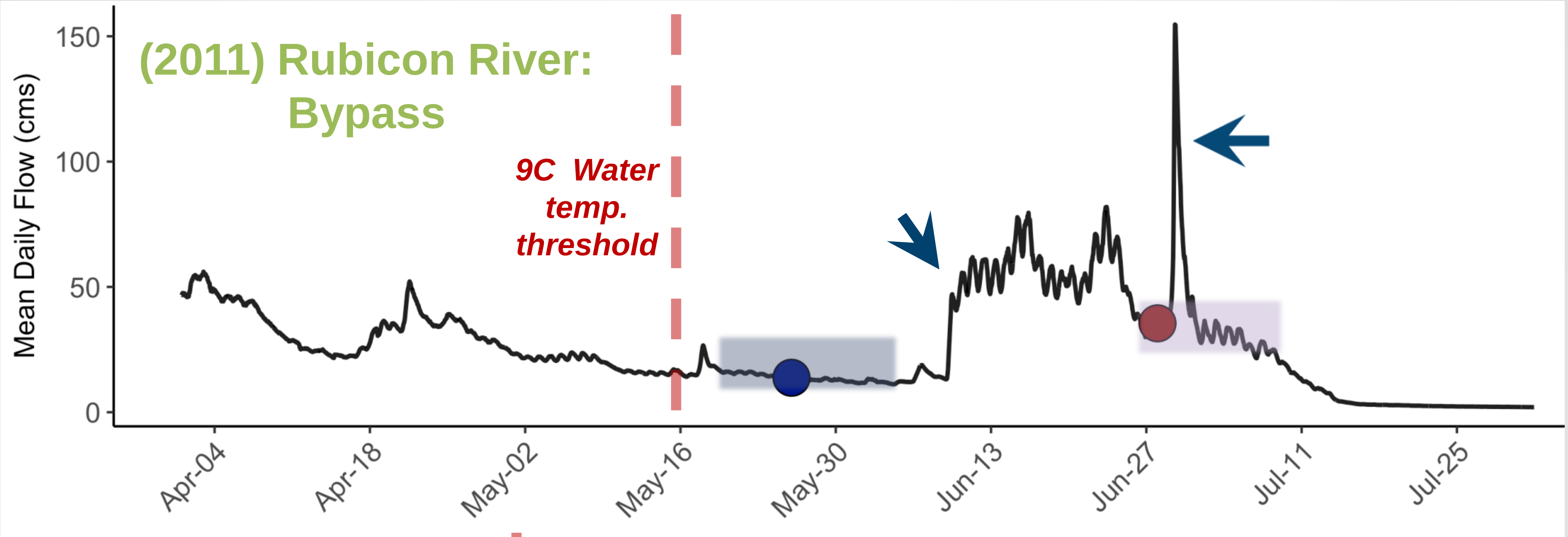
PREDICTABILITY VS SEASONALITY OF FLOW

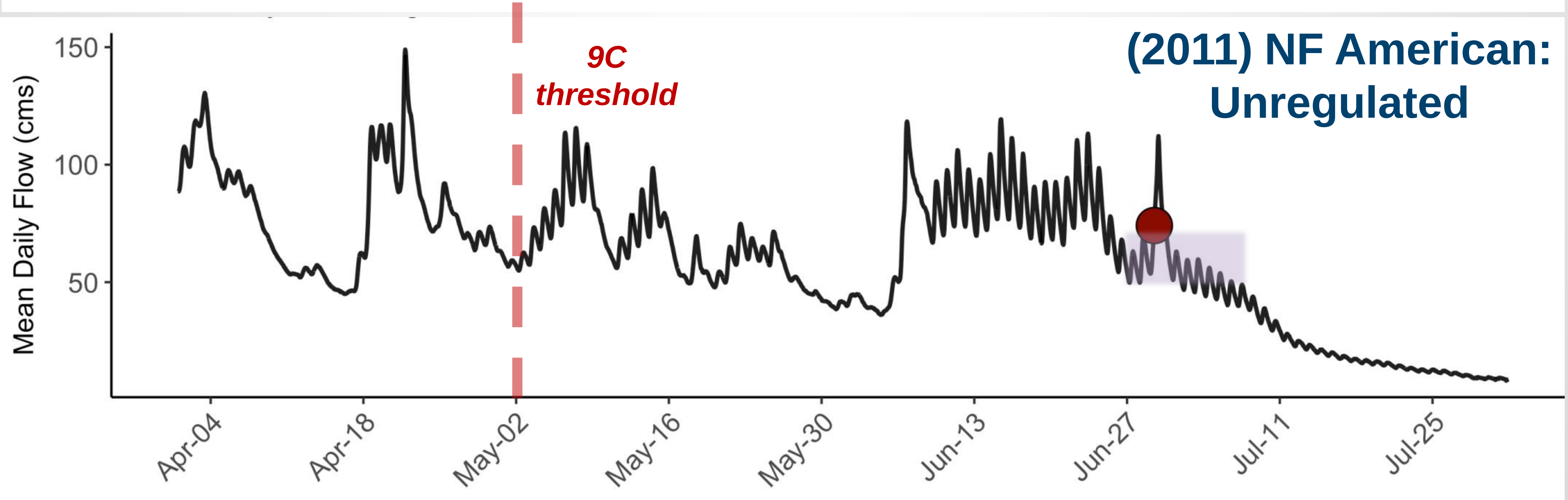


PREDICTABILITY VS SEASONALITY OF FLOW



Regulation can cause cue ASYNCHRONY





Breeding Timing Summary

- **Flow is a flexible spawning cue**
- **Water temperature might be more of a threshold (9 C)**
- Declining populations may struggle with mismatches from regulated flow regimes & climate change

BREAK
Thought Question

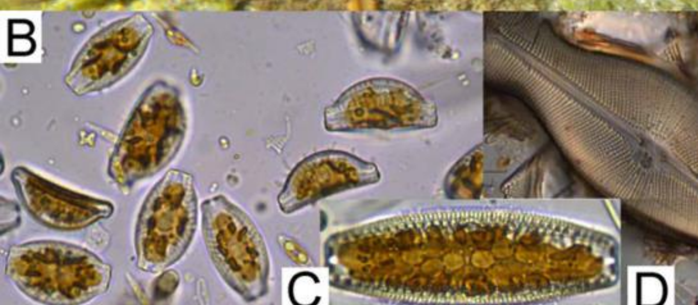
What criteria would you use to evaluate whether a dammed river is being responsibly managed?

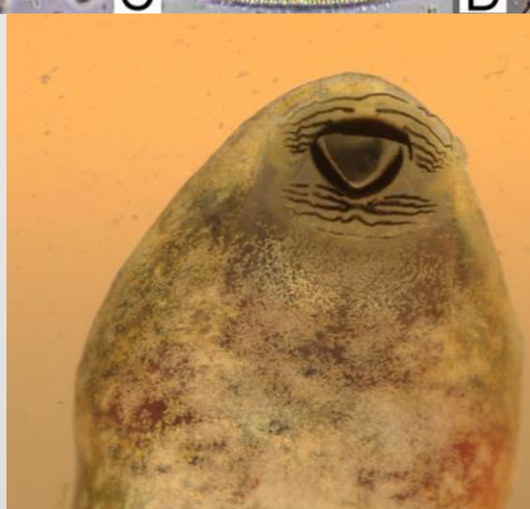
- Flows would be released to perform roughly the same ecological functions, even slightly scaled down, that the unimpaired river would perform.
- Geomorphic processes of sediment transport and deposition continue
- Riparian vegetation would go through natural cycles
- Species-specific ecological needs would be met
- Conservation target taxa are able to successfully complete their lifecycles
- An equitable balance is struck between the needs of people to drink, grow food, recreate, generate power and the needs of the river

Rana boylii

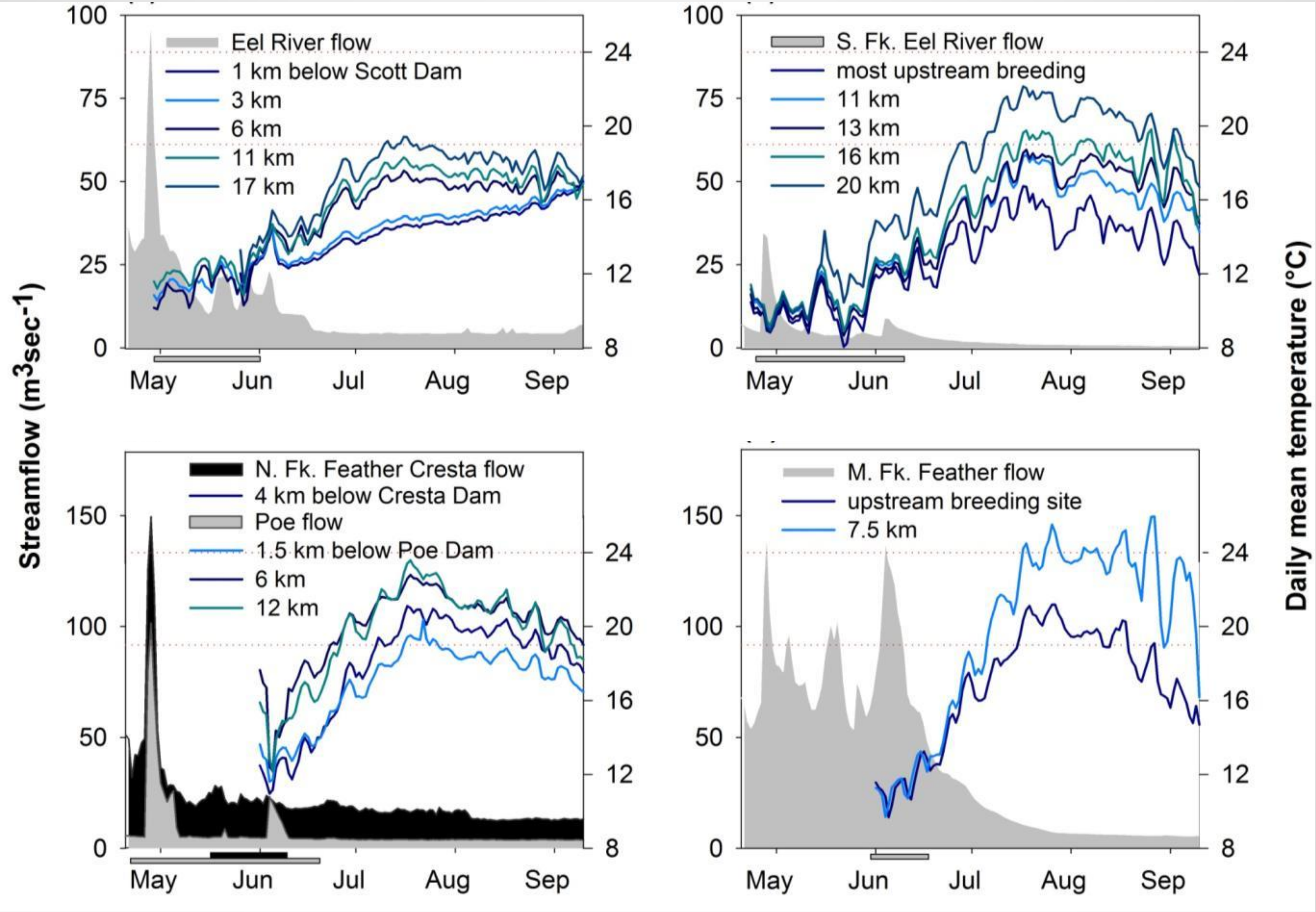
- Natural History
- Breeding Timing & Plasticity
- **Ecology**
- Conservation Genetics
- Population Dynamics

Tadpoles scrape algae where it is warm and flows not too swift



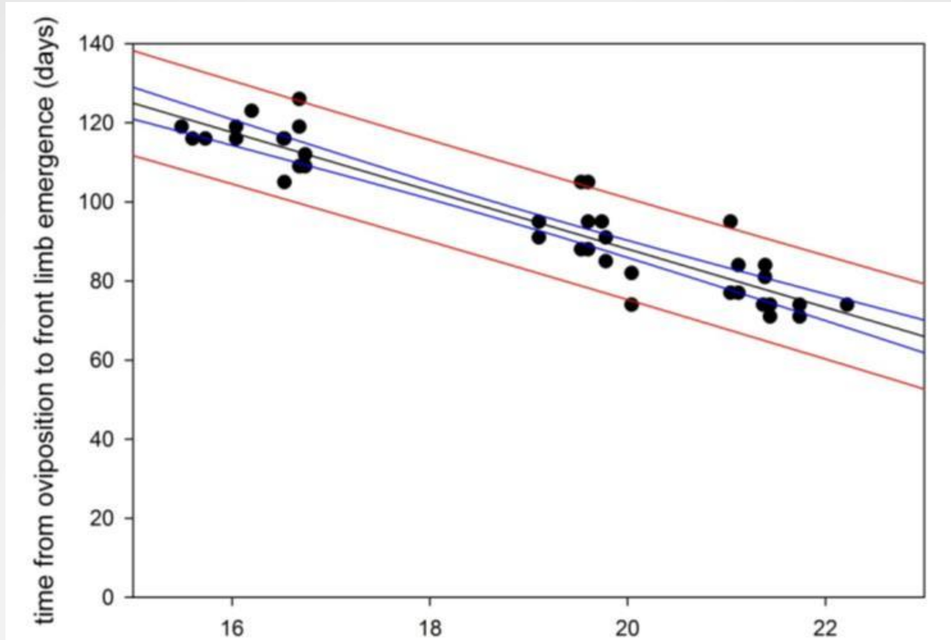


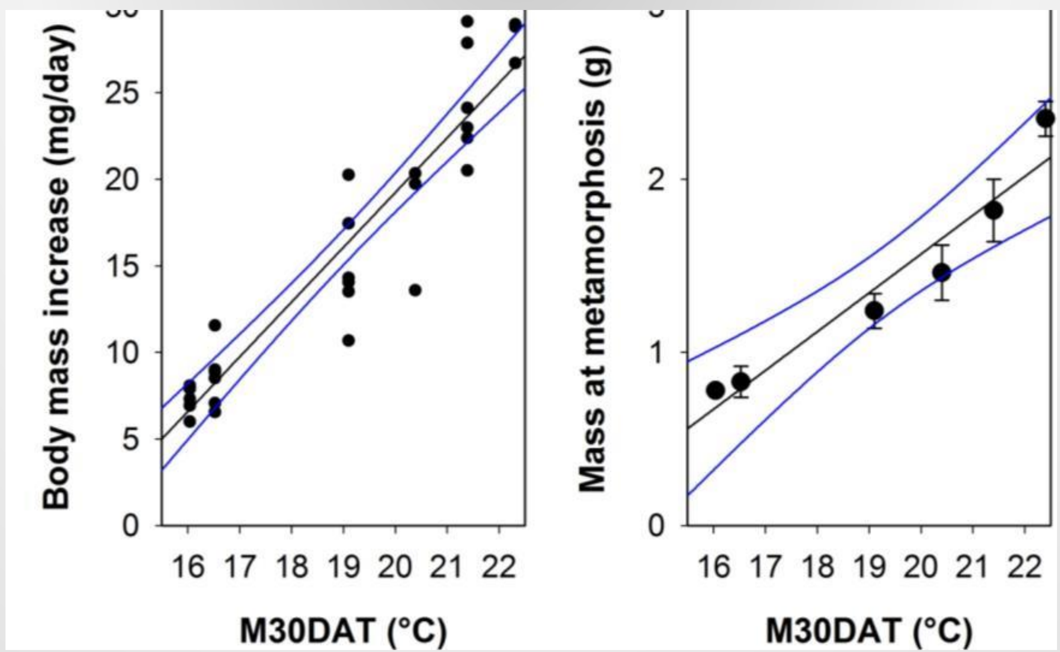
Altered versus natural summer temperature



Rearing experiments manipulating food and temp

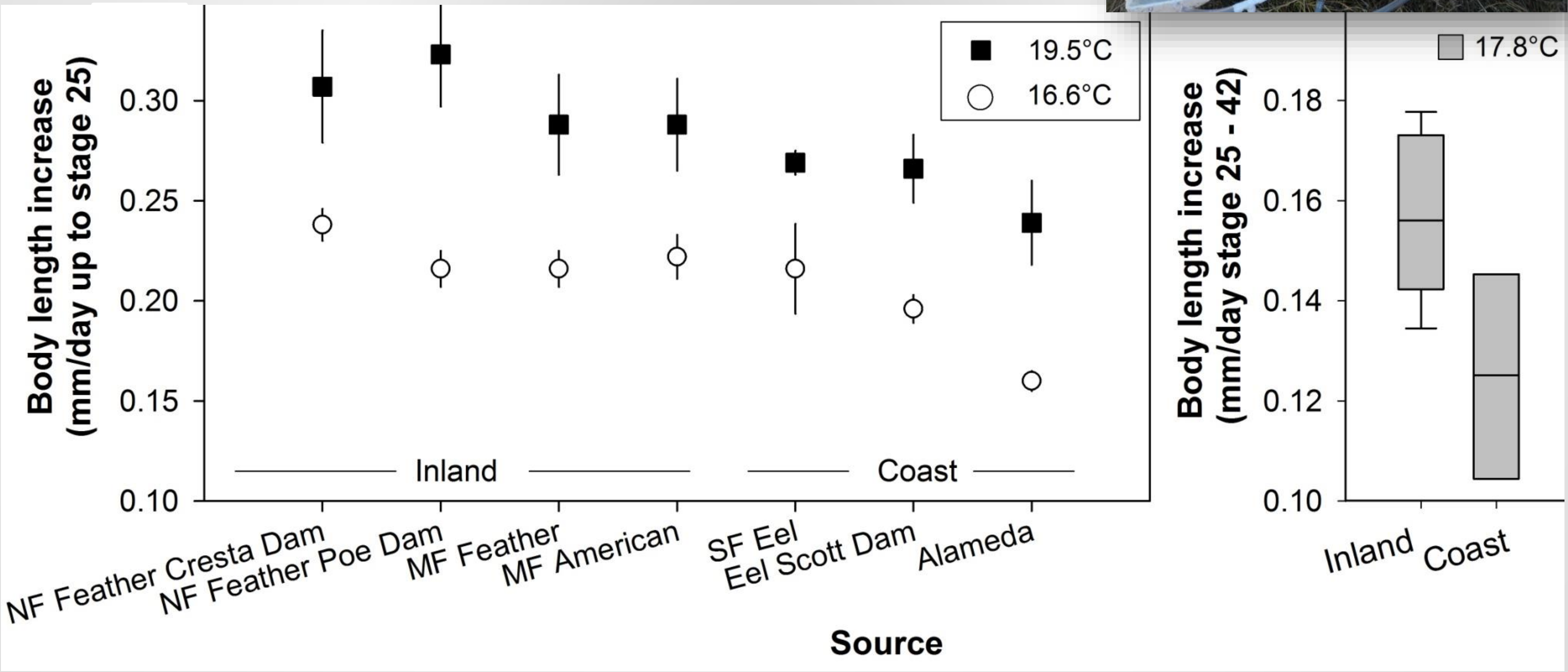
Thermal performance





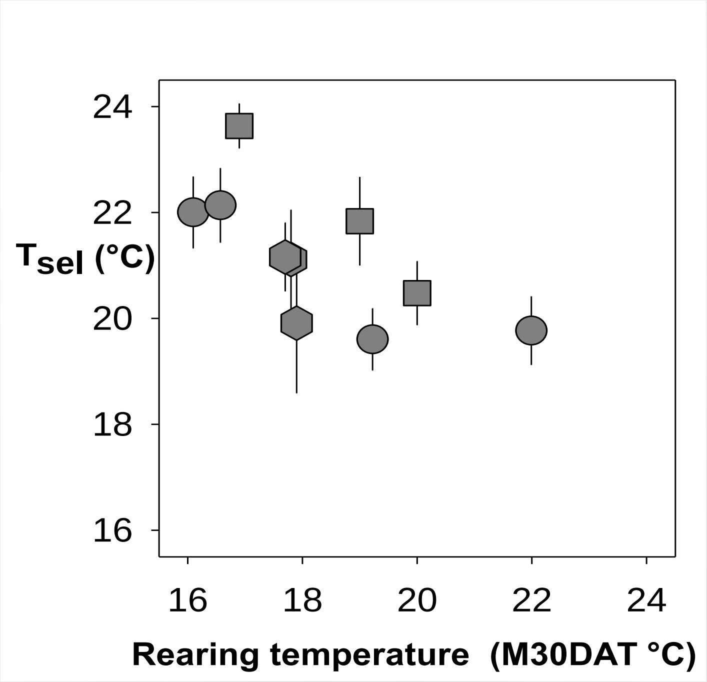
Common Garden Experiments

- Collected embryos from multiple populations
- Reared in growth chambers or re-circulating troughs
- Sierran genotypes have > intrinsic growth rates



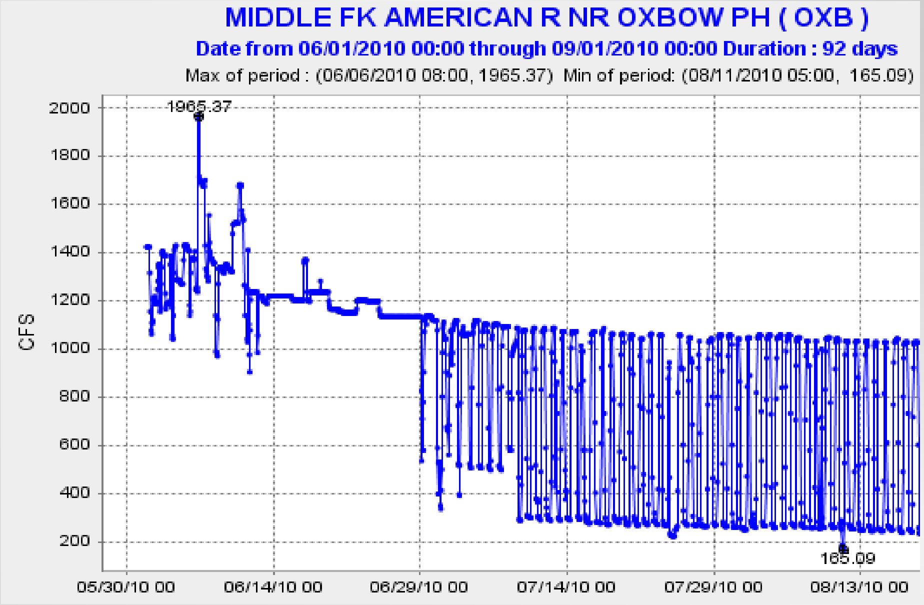
(Catenazzi and Kupferberg 2017)

Compensatory thermoregulation



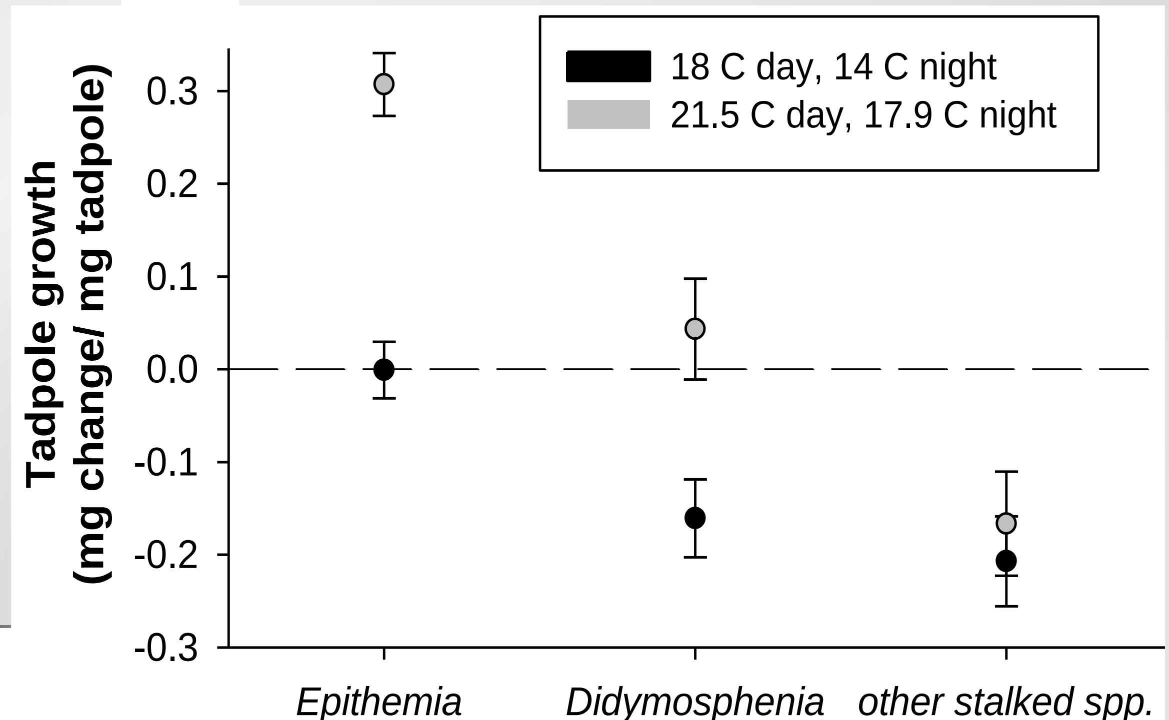
PERILS OF UNPALATABLE PERIPHYTON

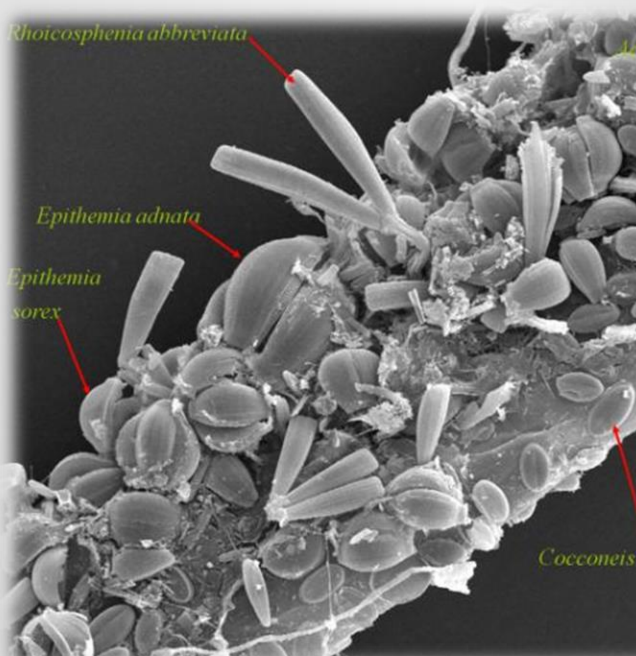
Didymosphenia, a.k.a 'rock snot' proliferating where flows fluctuate and cold water released from reservoir's bottom

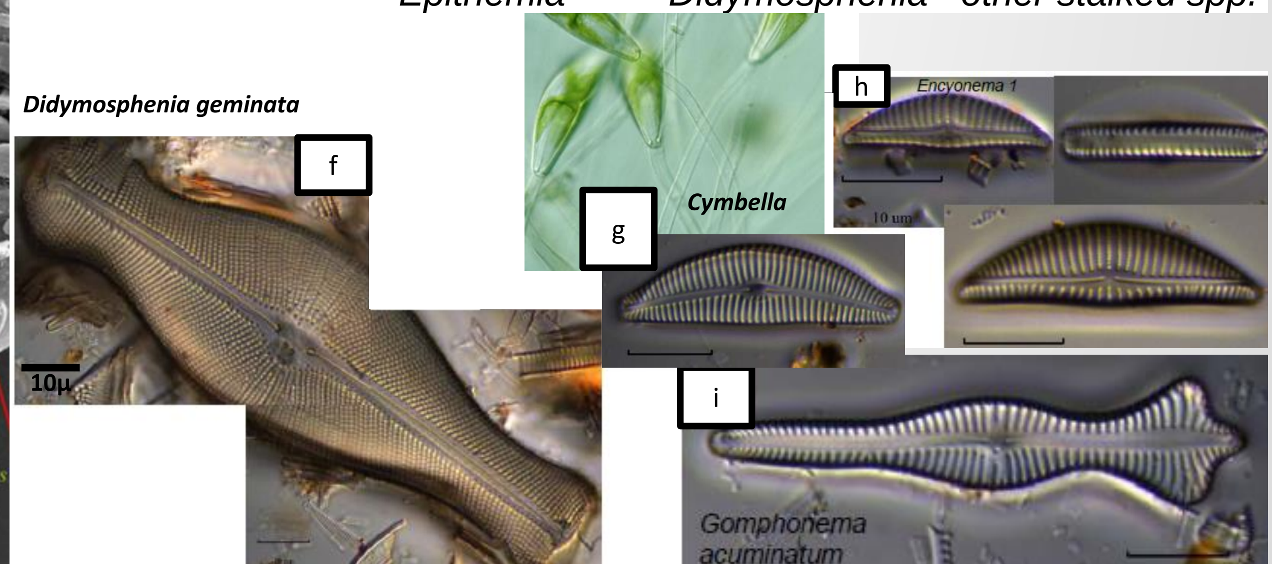


Collected periphyton covered cobbles in three rivers

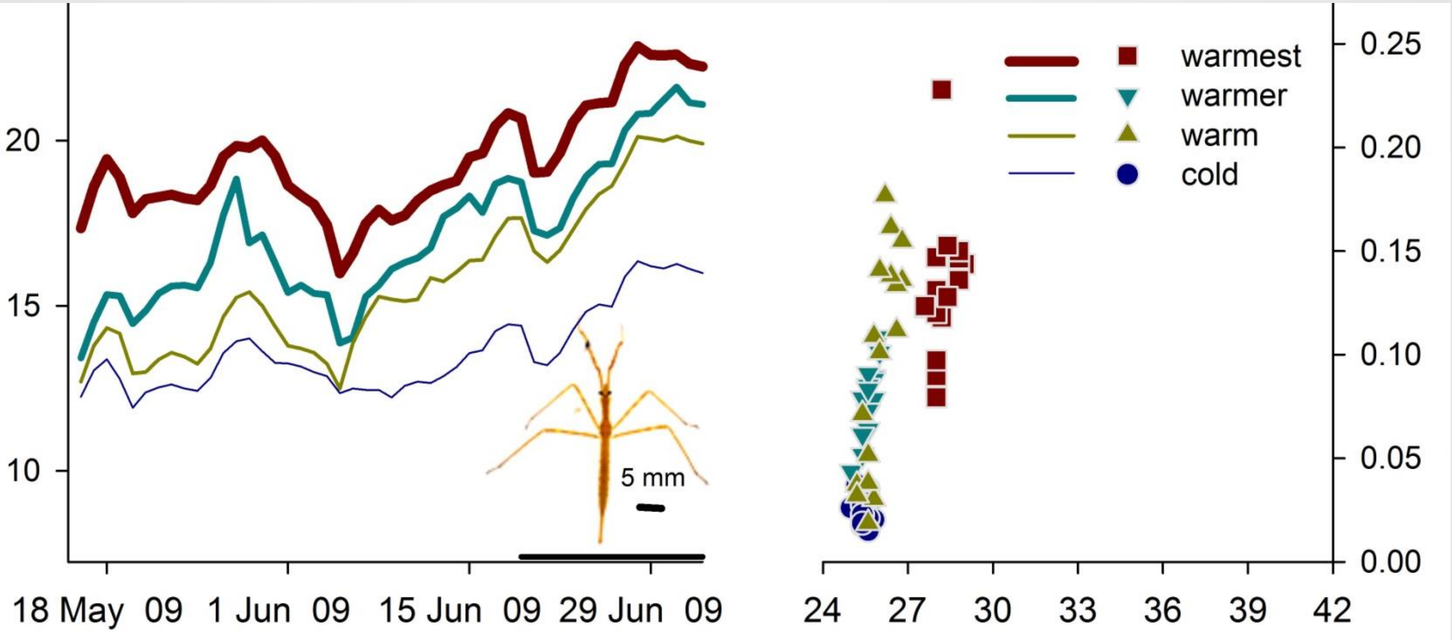
raised tadpoles in growth chambers where we controlled the temperature

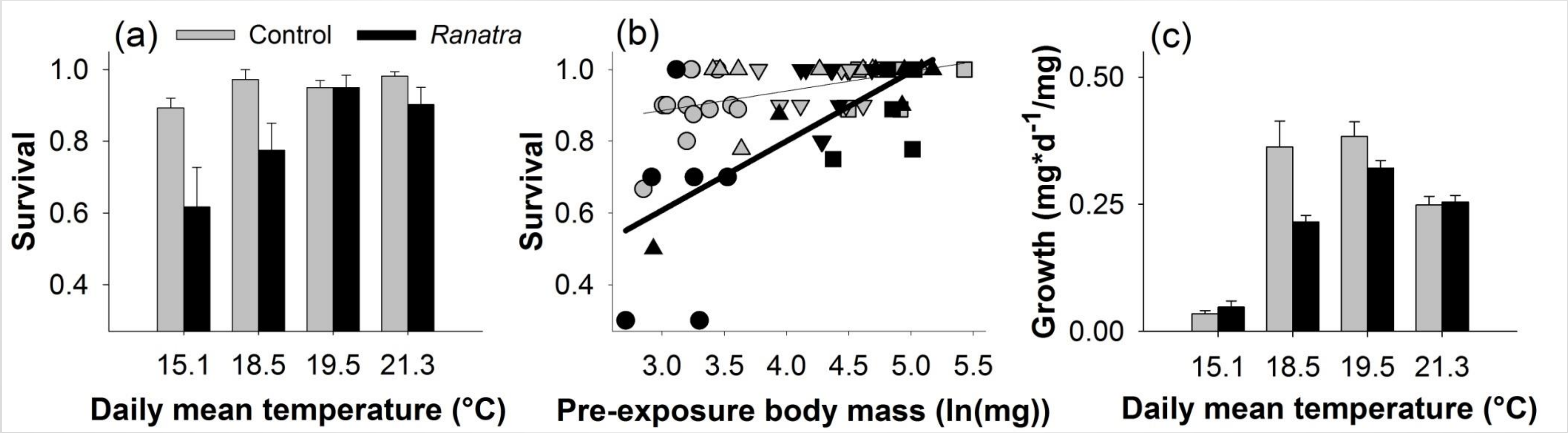






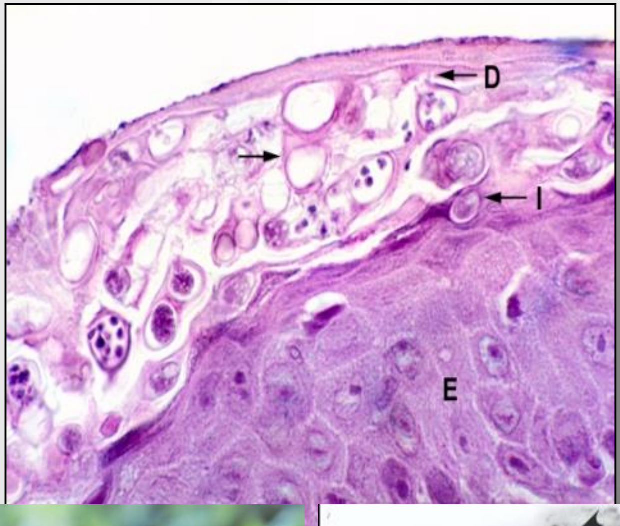
Temperature x predation





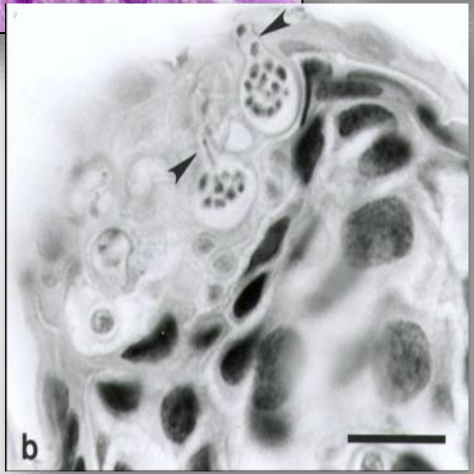
Disease

Batrachochytrium dendrobatidis (Bd)



Mountain yellow-legged frogs, Sierra Nevada Mountains, CA

Foothill yellow-legged frog Alameda Creek, CA



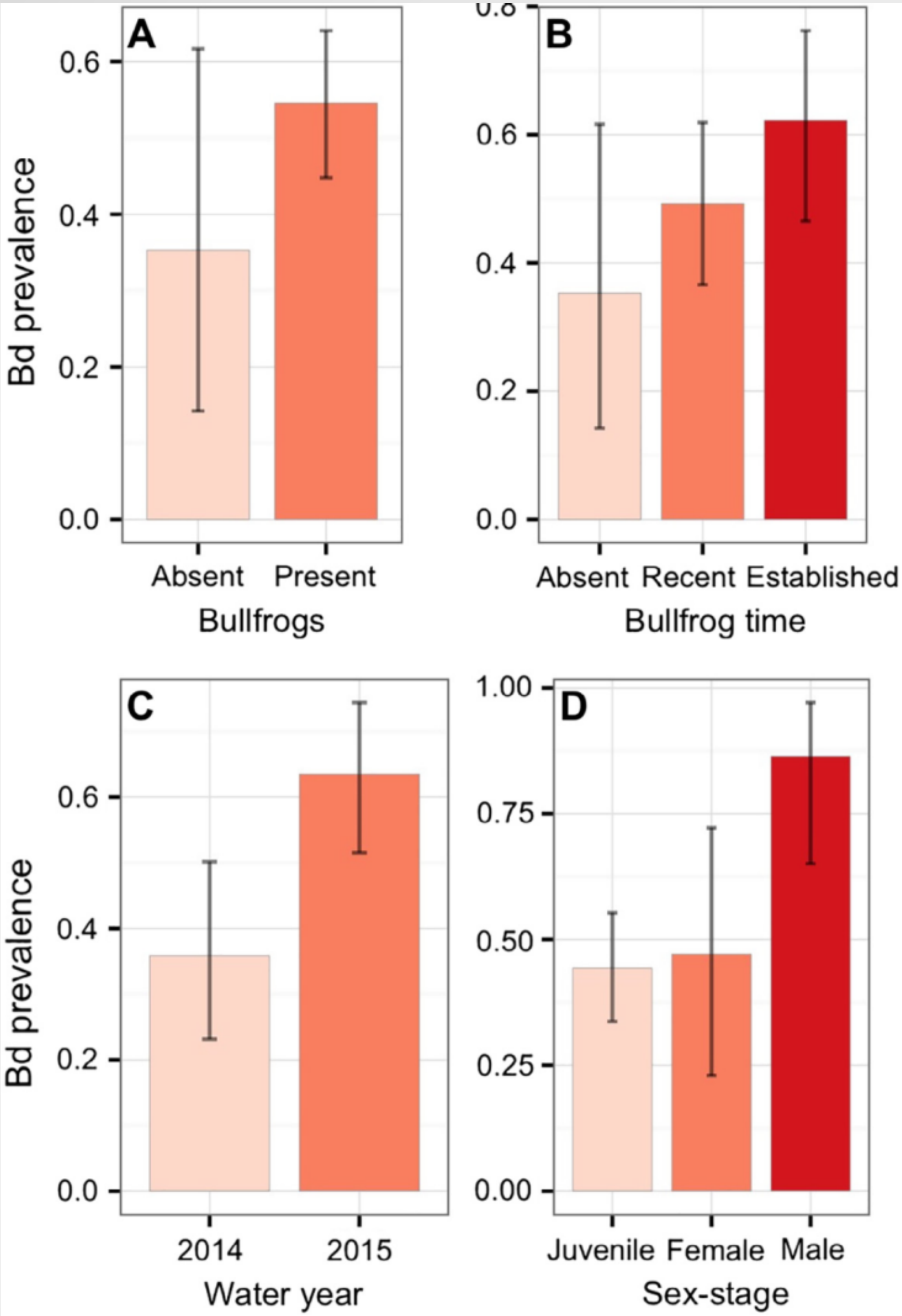
Alameda Creek

Frog distribution and abundance shifted in the drought

Field Sampling – 2 years post outbreak
all spp Bd positive



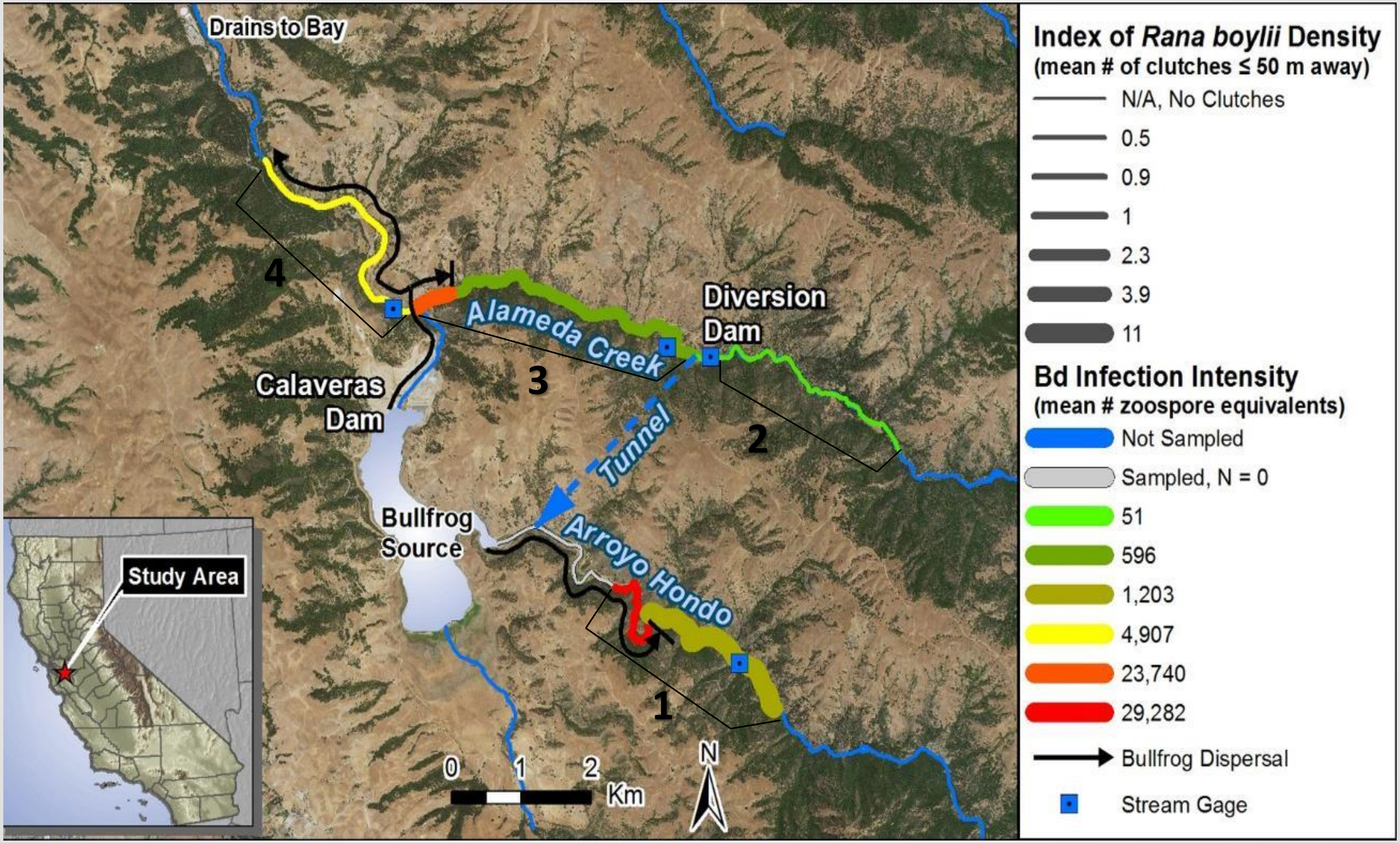




Prevalence

- > with bullfrogs
- Increased as drought progressed
- Greatest in males

Spatial variation in Infection Intensity
Correlated w/ bullfrogs, con-specific density



Conclusions from mixed modeling

- prevalence
  - Sex/stage (males)
  - Bullfrogs
    - Reservoir and vector
  - Water year
- load
  - Mean daily stream flow
    - Dilution effect?
  - Bullfrogs
  - Season, highest in fall
  - Con-specific density

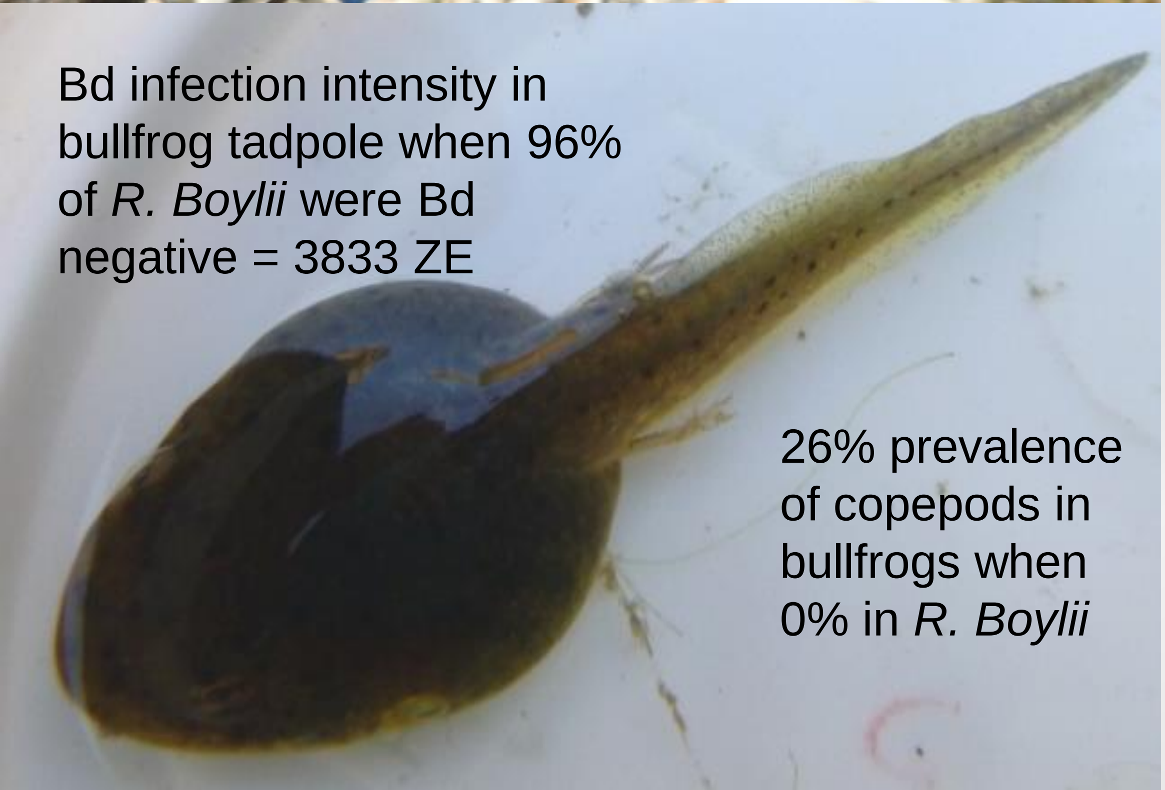
S. Bobzien

R. boylii persists after the outbreak

but…

Bullfrogs ⇧

- Predators
- Competitors
- Vectors/reservoirs
  - Copepod parasites
  - Chytrid fungus



BREAK

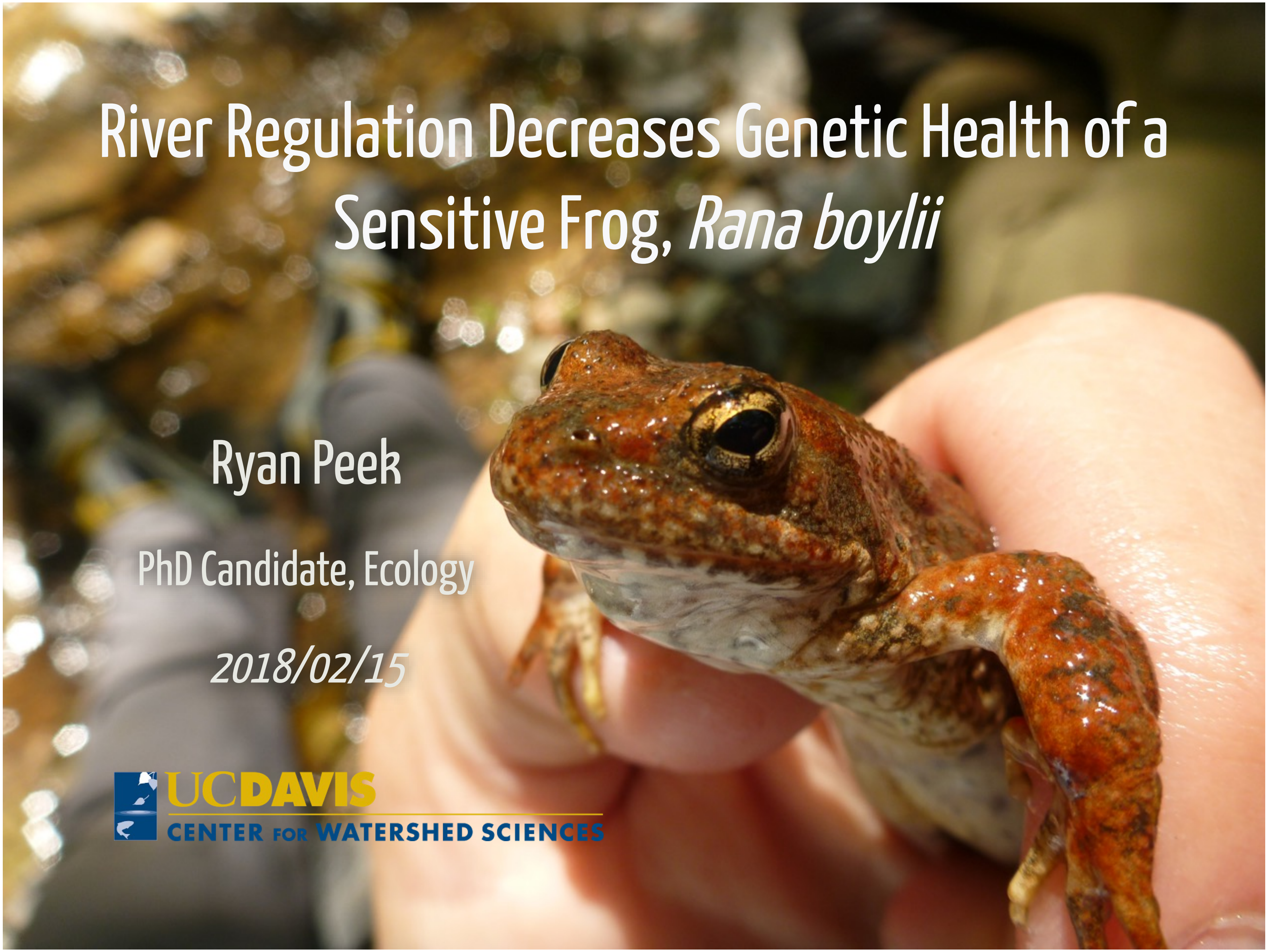
Thought Question

How would you incorporate knowledge of ecological interactions when making a mitigation or relocation plan?

- Keep individuals in separate bags/containers to prevent spread of Bd or other disease
- Time relocations to avoid periods of high Bd loads
- Take care not to create areas of high density when relocating
- Consider food resources and temperature

Rana boylii

- Natural History
- Breeding Timing & Plasticity
- Ecology
- **Conservation Genetics**
- Population Dynamics


River Regulation Decreases Genetic Health of a Sensitive Frog, *Rana boylii*
Ryan Peek
PhD Candidate, Ecology
2018/02/15
UCDAVIS
CENTER FOR WATERSHED SCIENCES

Acknowledgements

- Mike Miller & Sean O'Rourke
- Center for Watershed Sciences
- Brad Shaffer
- Amy Lind
- Corey Luna, many field helpers, SYRCL, Sierra Streams Institute

"The face of the water, in time, became a wonderful book--a book that was a dead language to the uneducated passenger, but which told its mind to me without reserve... And it was not a book to be read once and thrown aside, for it had a new story to tell every day” (*Mark Twain, Two Views of the Mississippi, 1883*)

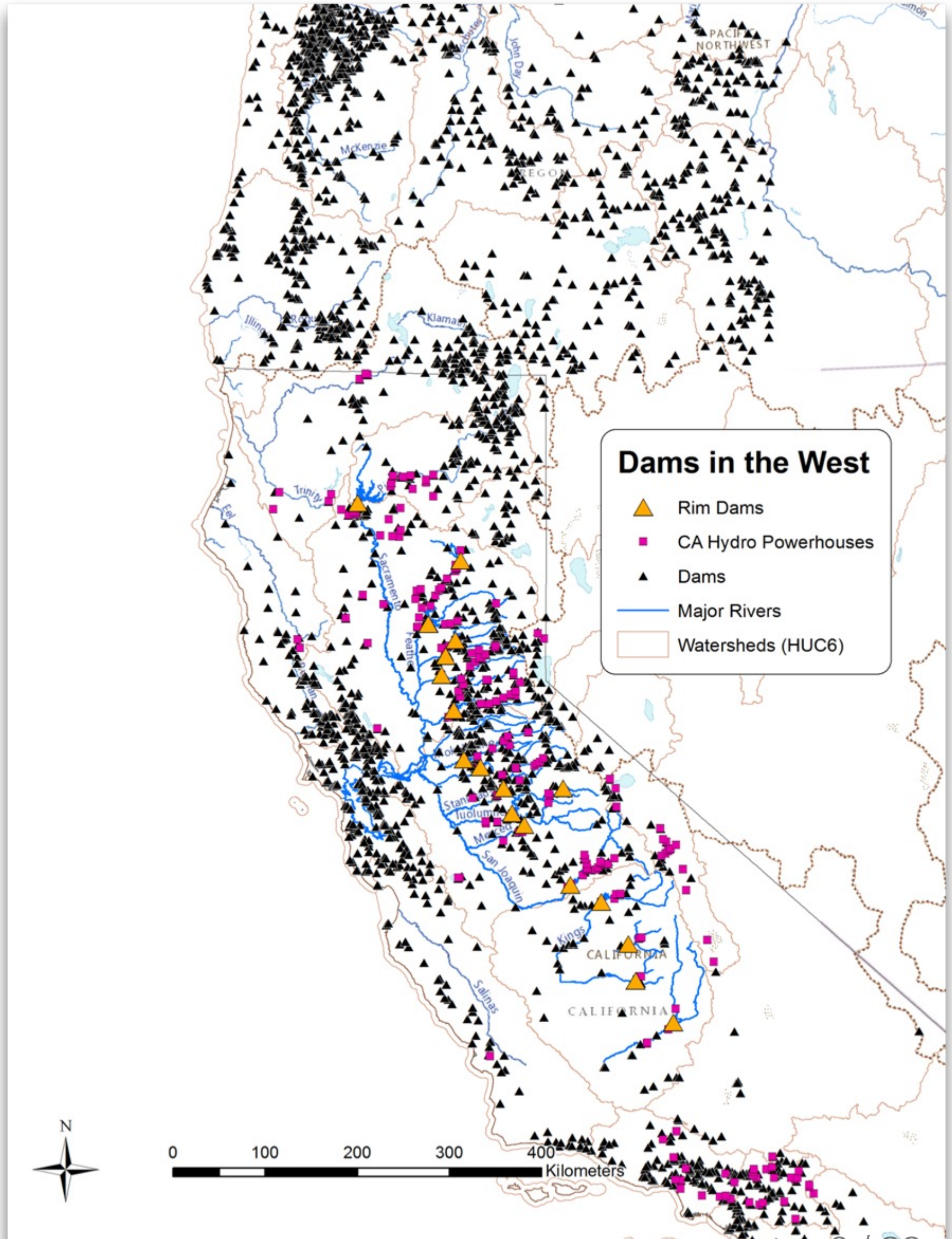
The abridged history of Sierra Nevada Rivers

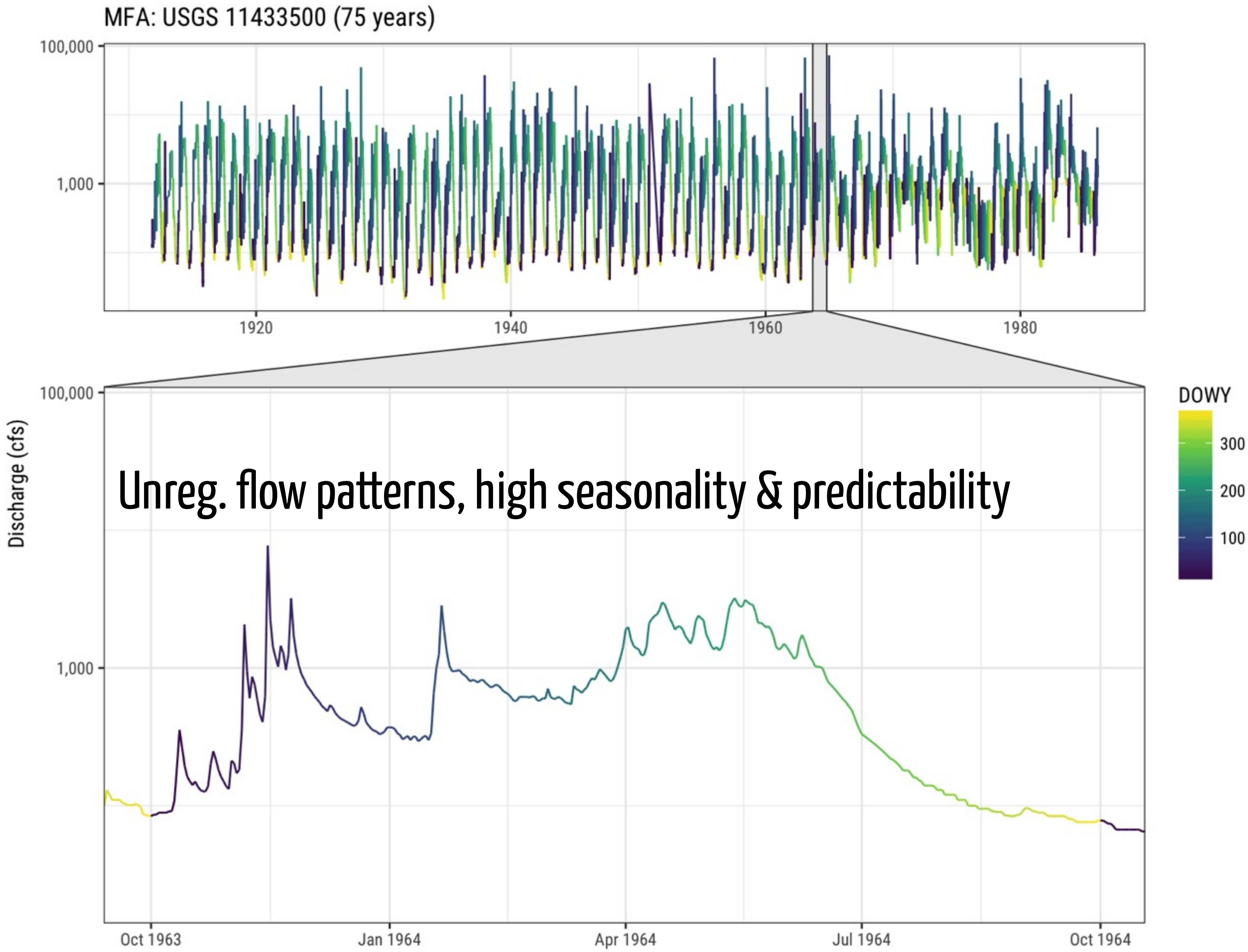
- Rivers flow largely uninterrupted for 20,000+ years
- Hydraulic Mining begins in 1853, banned in 1884.
- Regulation via dams/diversion/hydropower (1930's-today)

CA Anthropogenic Legacy: Mining

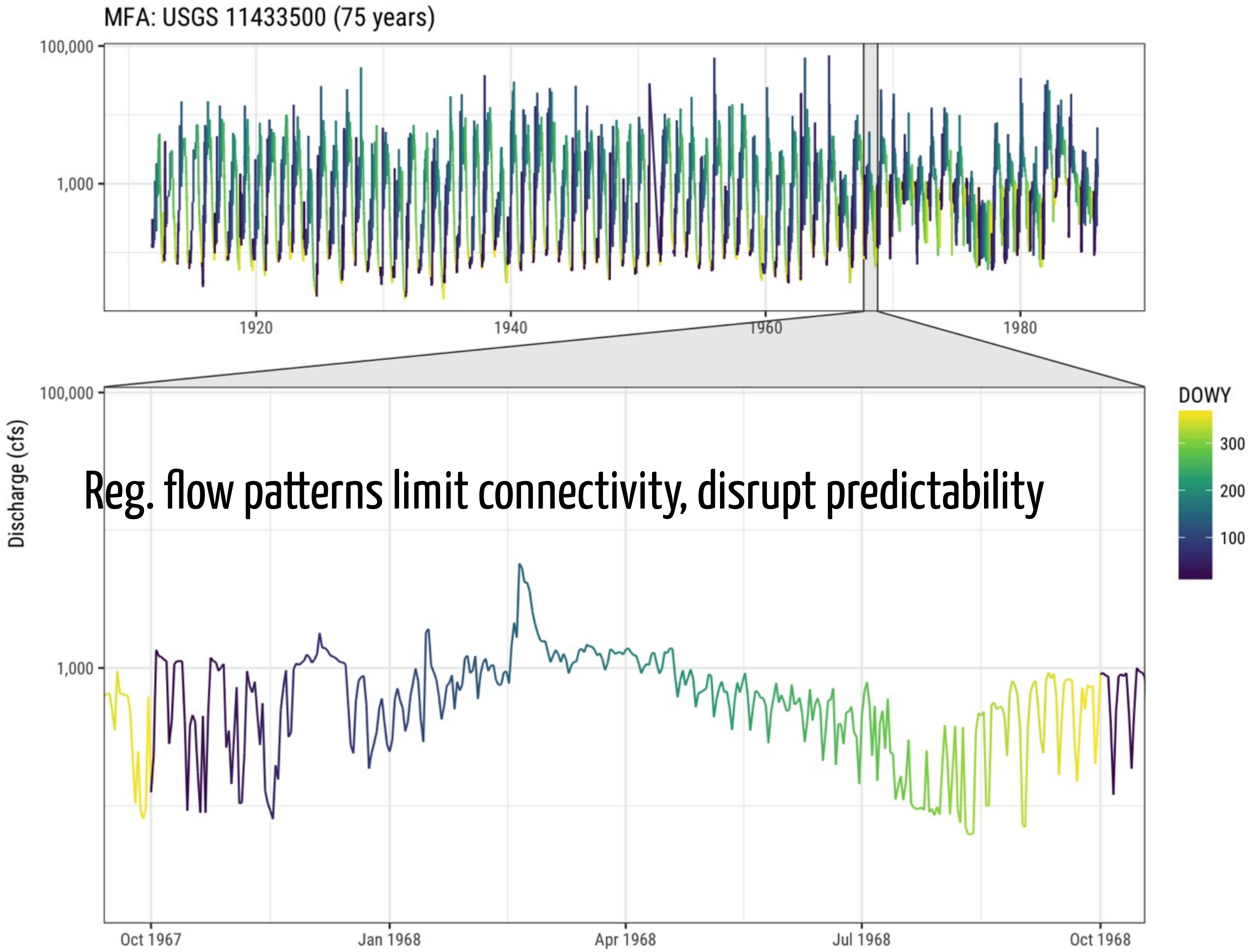
CA Dammed Rivers

- **Over 1,400 large dams (NID 2007)**
- **Residential energy demands expected to increase by 24% by 2035 (US EIA 2010)**

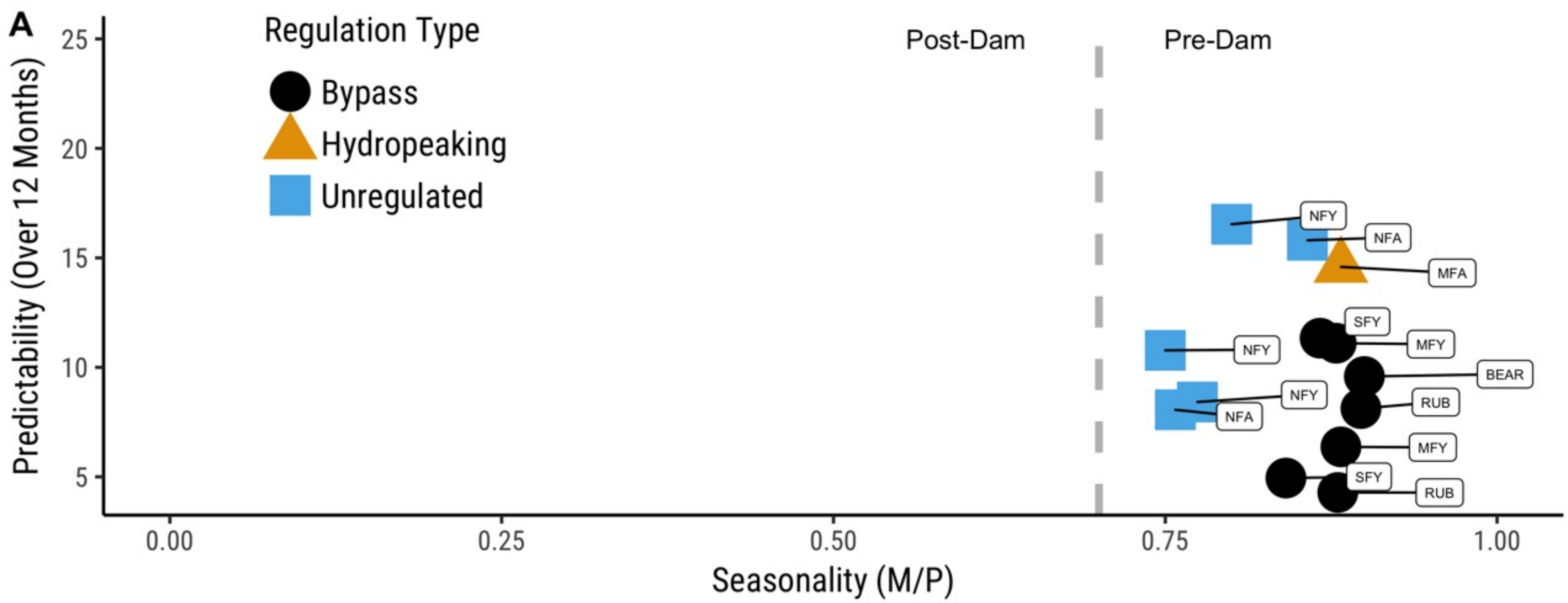



MFA: USGS 11433500 (75 years)
100,000
1,000
1920
1940
1960
1980
Discharge (cfs)
100,000
1,000
Unreg. flow patterns, high seasonality & predictability
Oct 1963
Jan 1964
Apr 1964
Jul 1964
Oct 1964
DOWY
300
200
100

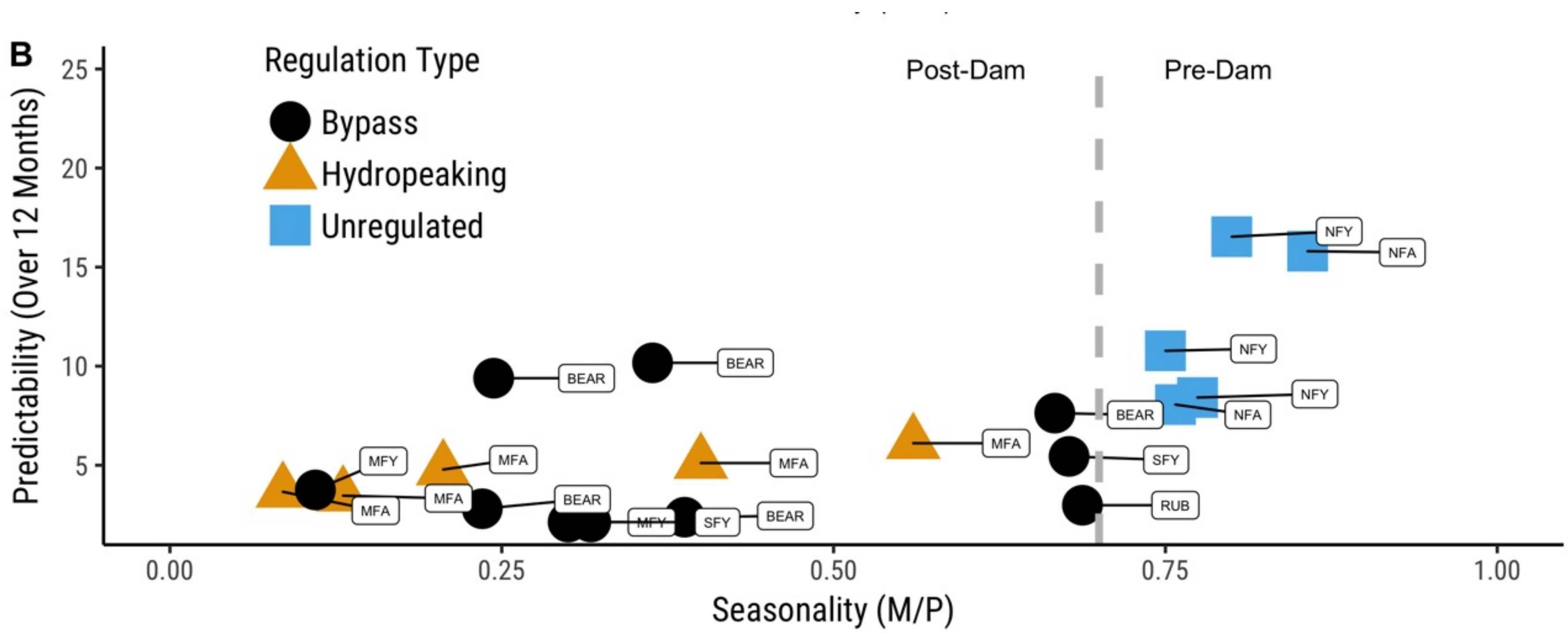
Reg. flow patterns limit connectivity, disrupt predictability



Pre-Dam Data from USGS



Post-Dam Data from USGS

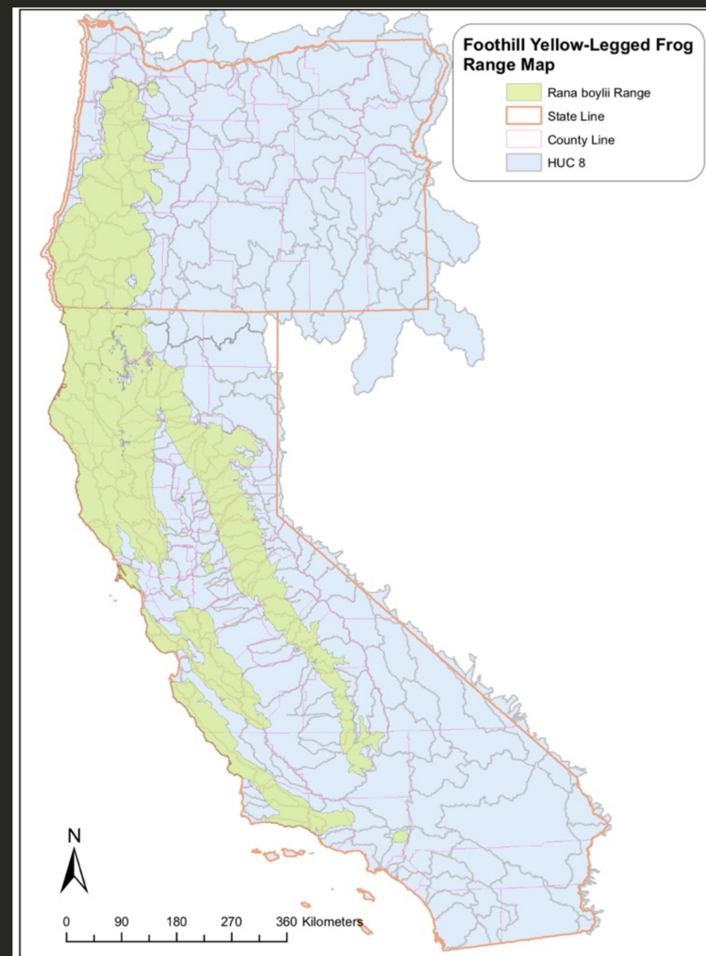


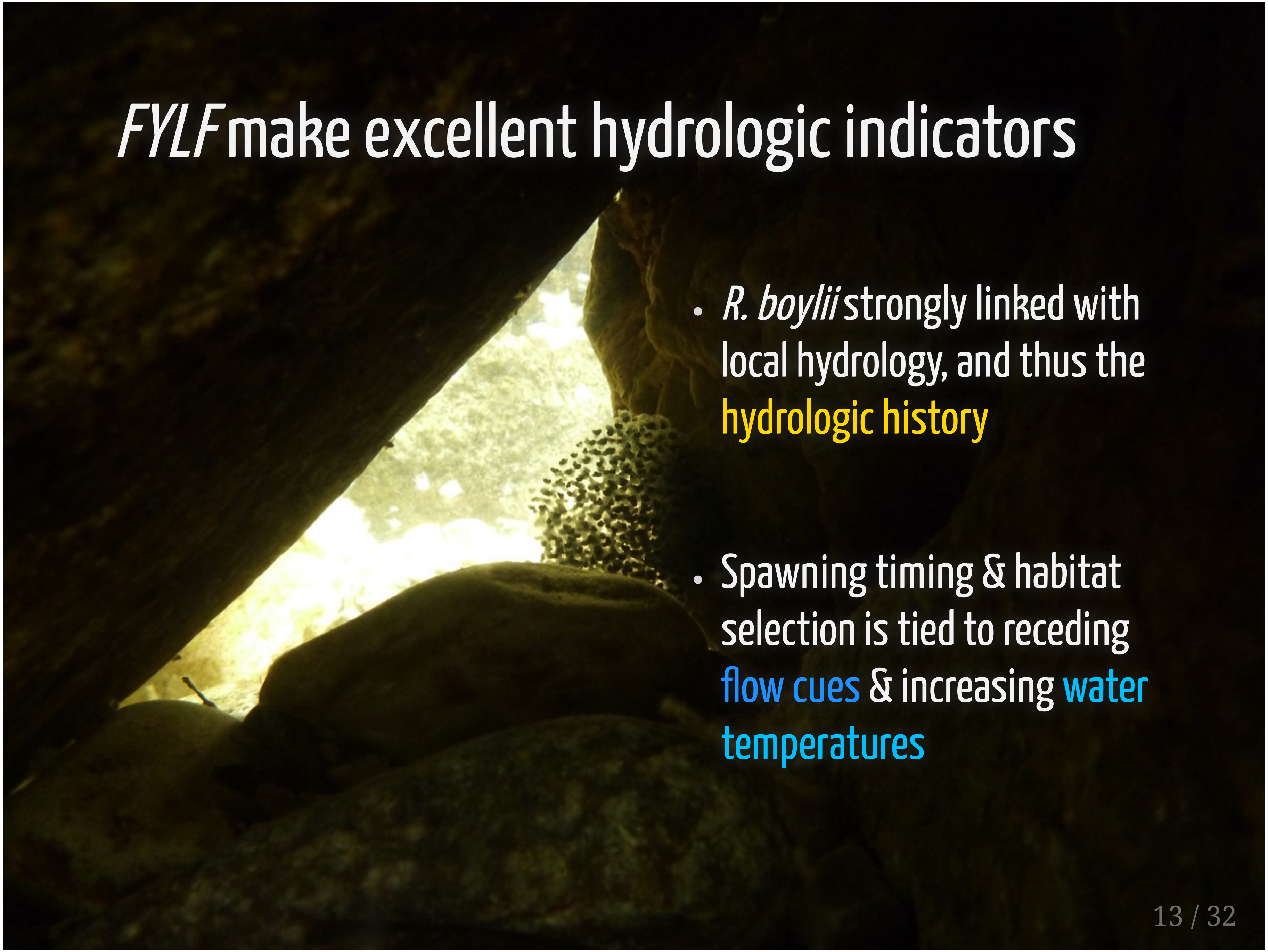

Small populations with limited connectivity may have reduced
adaptive potential, or genetic health

Foothill yellow-legged frogs (*Rana boylii*)

- Obligate river breeding frog, uses wide range of habitat, but has disappeared from over 50% of historical range

- Being evaluated as candidate for state and federal listing under ESA





FYLF make excellent hydrologic indicators

- *R. boylii* strongly linked with local hydrology, and thus the hydrologic history
- Spawning timing & habitat selection is tied to receding flow cues & increasing water temperatures

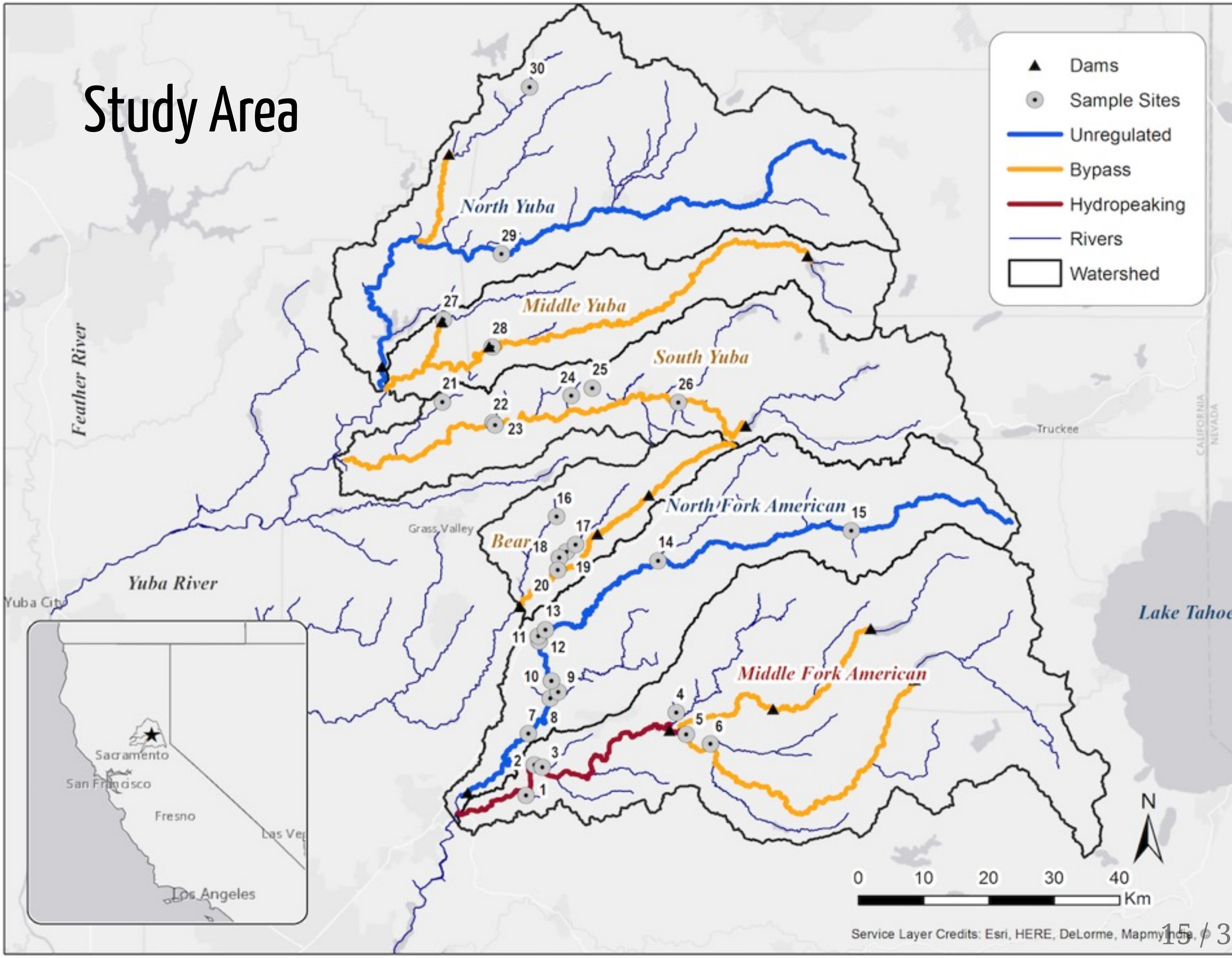
Study

Has river (flow) regulation caused genetic fragmentation in *R. boylii*?

Can we quantify this genetic signature for specific hydrologic flow regimes?

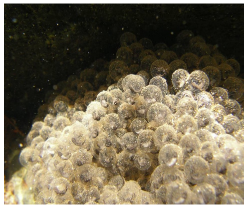
- Use genome-wide methods RADSeq/RAPTURE (*Ali et al. 2016*)

Study Area



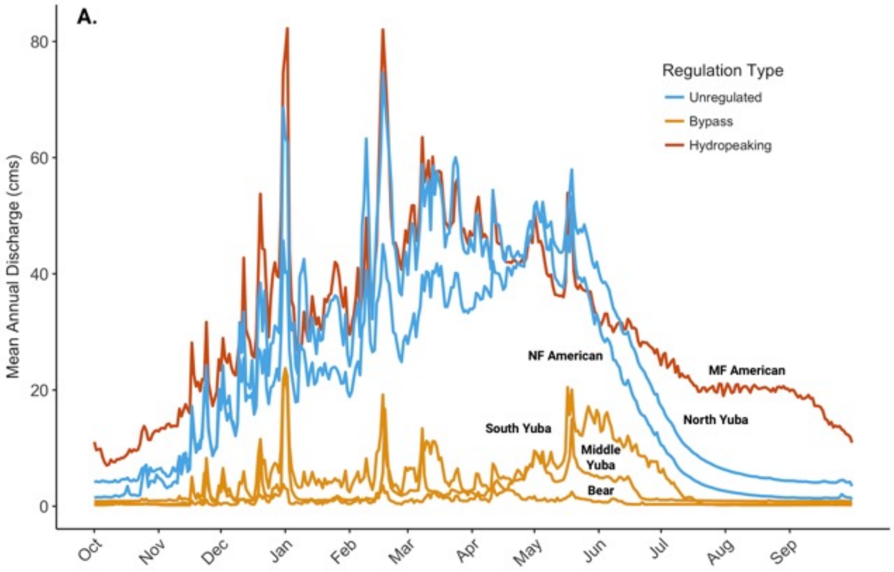
Dams
Sample Sites
Unregulated
Bypass
Hydropeaking
Rivers
Watershed
North Yuba
Middle Yuba
South Yuba
North Fork American
Middle Fork American
Bear
Feather River
Yuba River
Lake Tahoe
Truckee
Grass Valley
Yuba City
Sacramento
San Francisco
Fresno
Los Angeles
0 10 20 30 40
Km
N
Service Layer Credits: Esri, HERE, DeLorme, Mapmyindia, ©

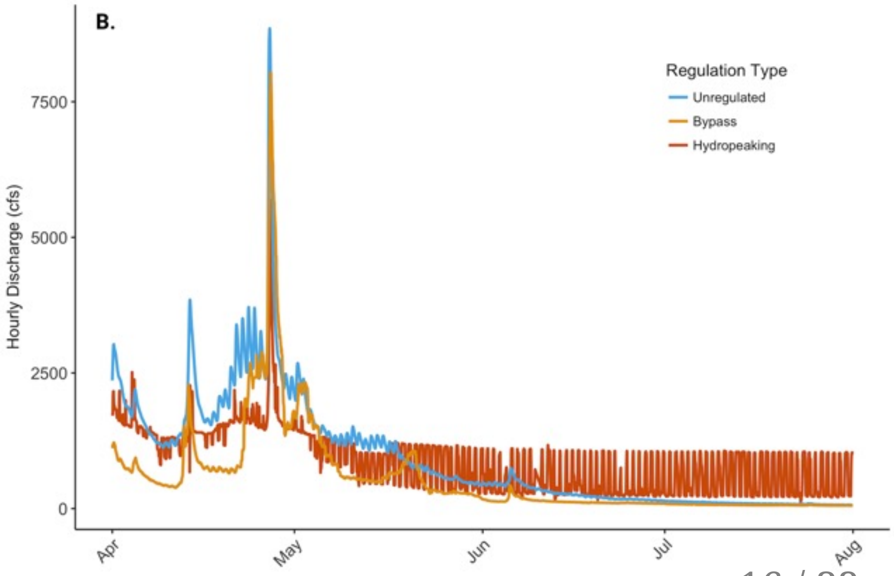
Annual and Hourly Flows by Regulation Type



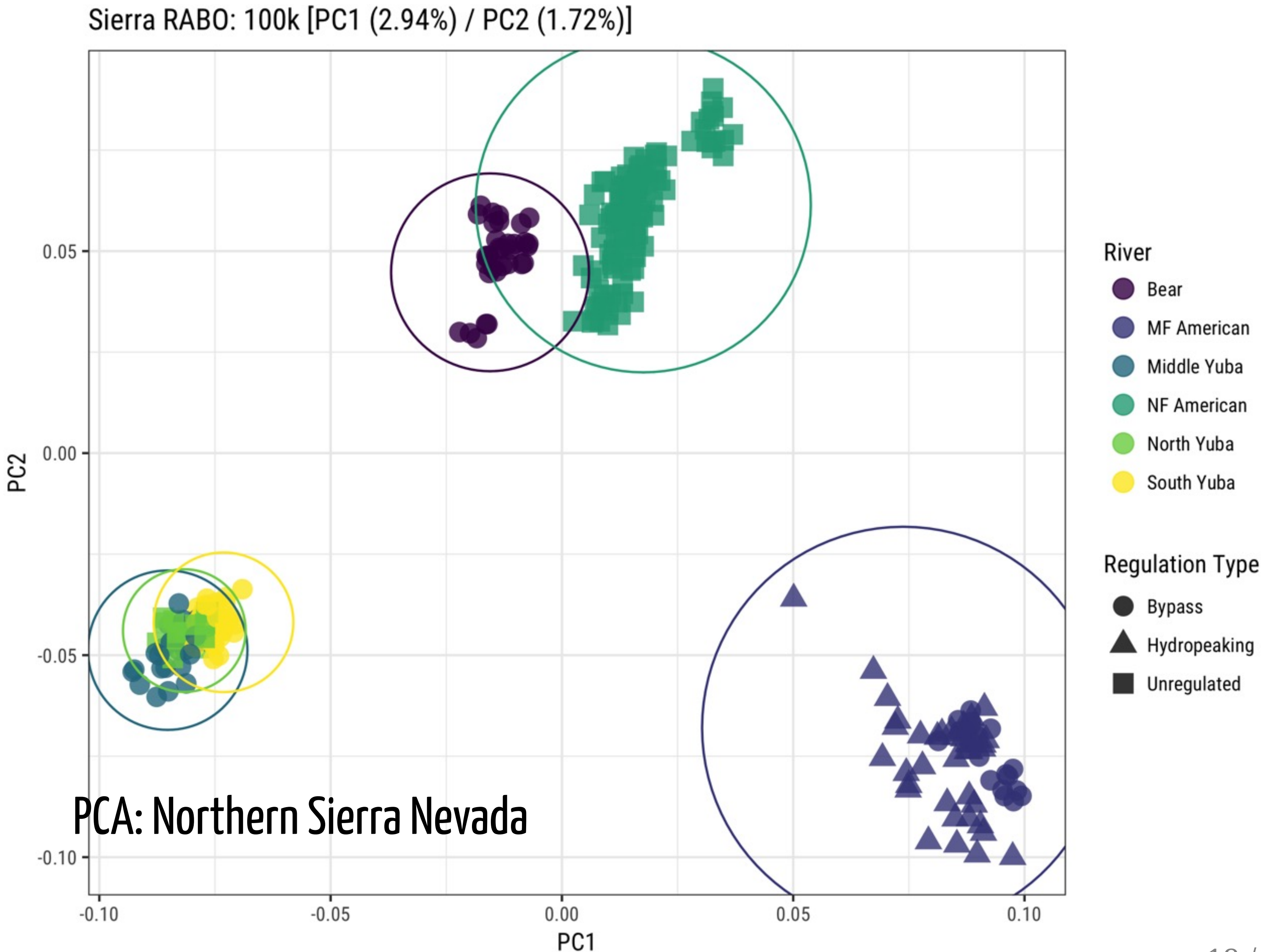
Egg Deposition Timing Matters…

To avoid scour or dessication

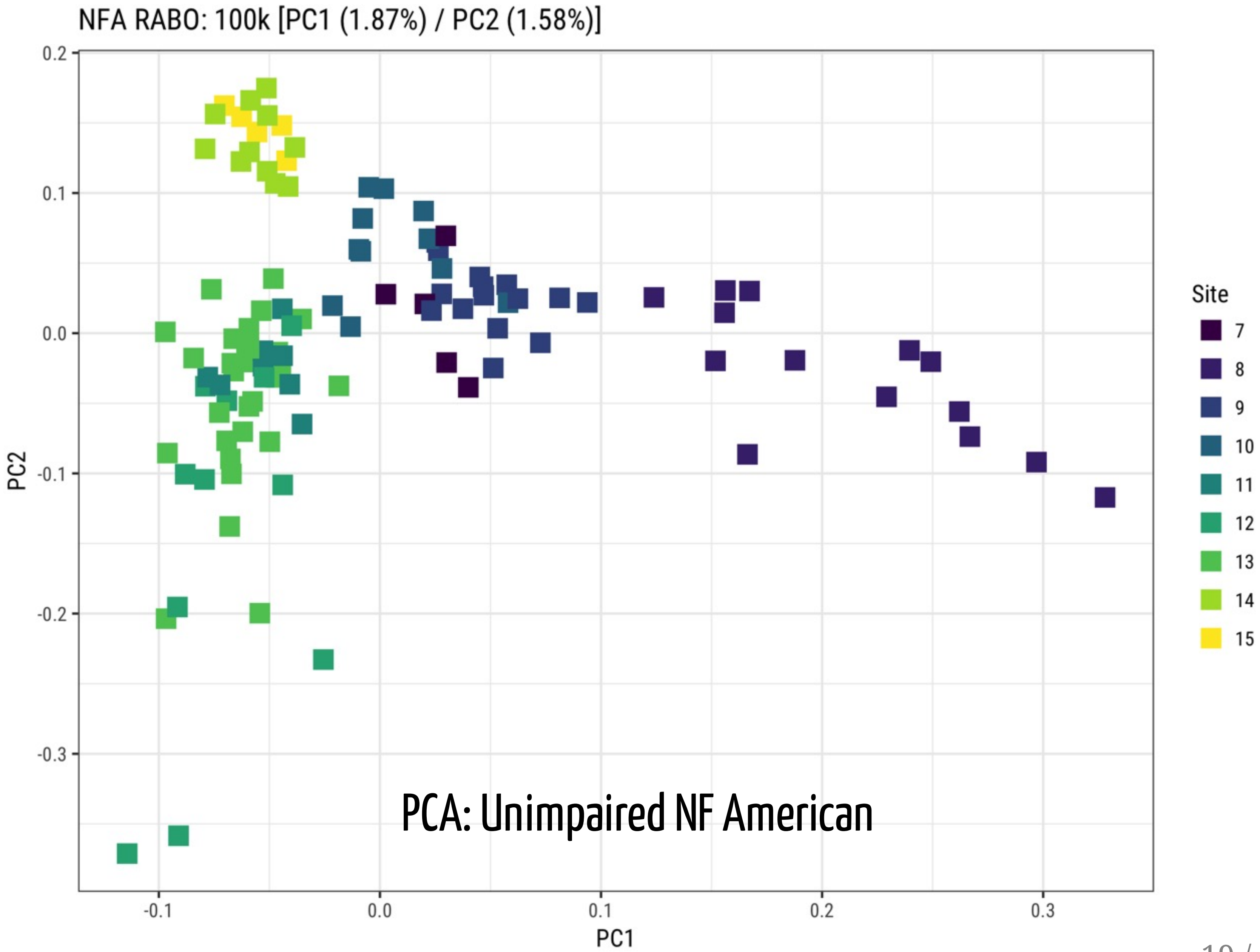


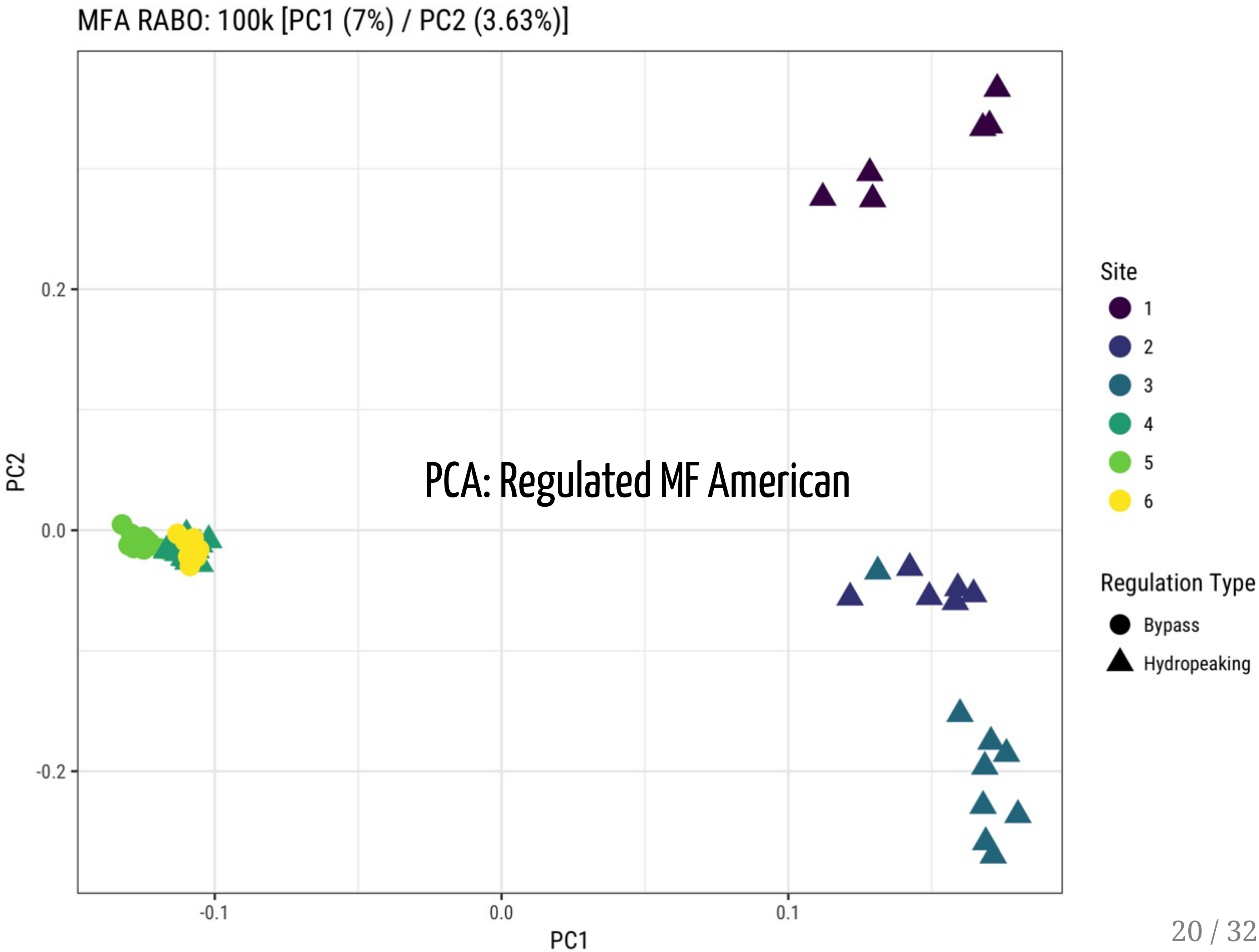


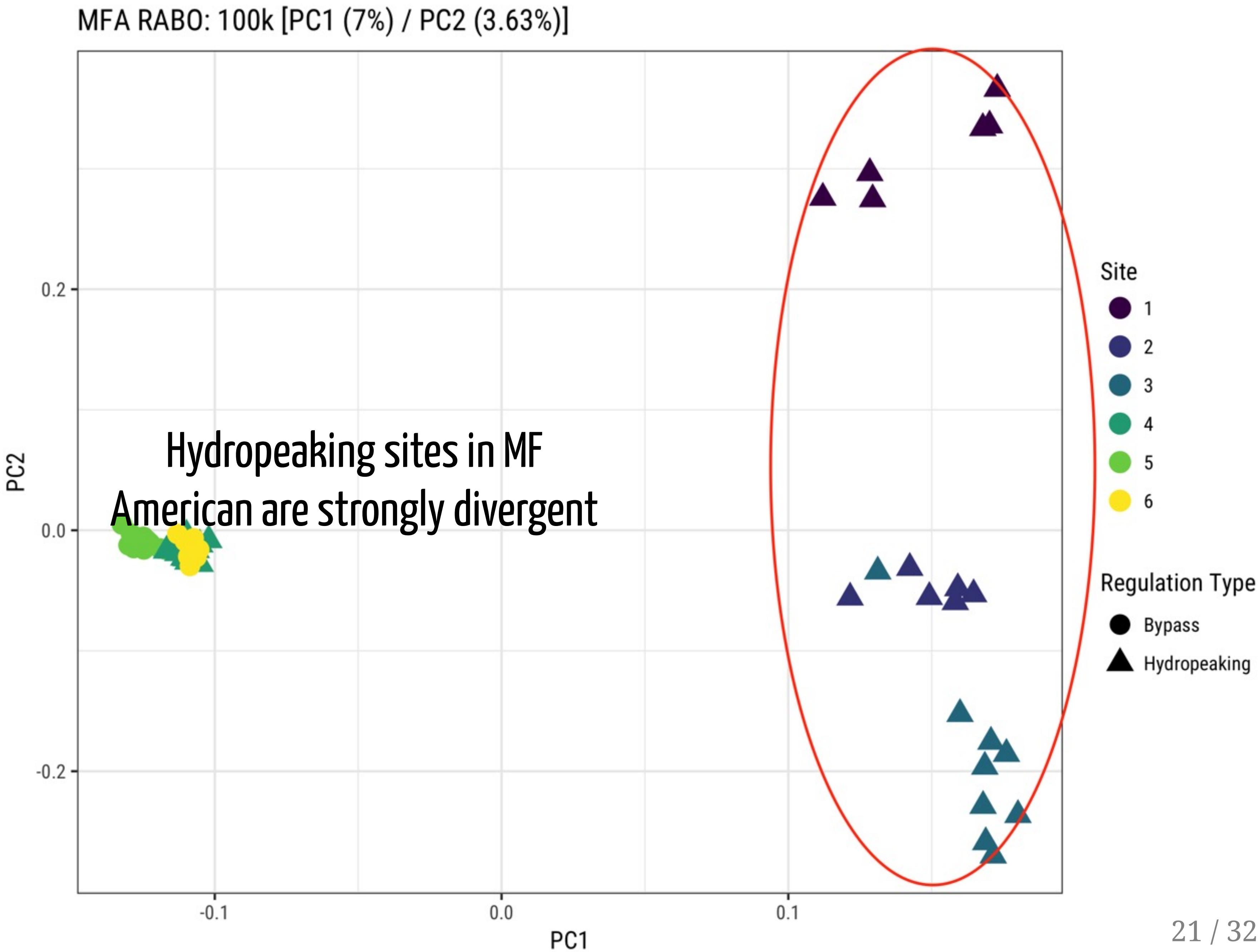
RESULTS: Anomolous genetic pattern in highly regulated MF American watershed



PCA: Northern Sierra Nevada


NFA RABO: 100k [PC1 (1.87%) / PC2 (1.58%)]
PC1
PC2
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.1
0.0
0.1
0.2
0.3
Site
7
8
9
10
11
12
13
14
15
PCA: Unimpaired NF American


MFA RABO: 100k [PC1 (7%) / PC2 (3.63%)]
PC2
0.2
0.0
-0.2
PC1
-0.1
0.0
0.1
PCA: Regulated MF American
Site
1
2
3
4
5
6
Regulation Type
Bypass
Hydropeaking

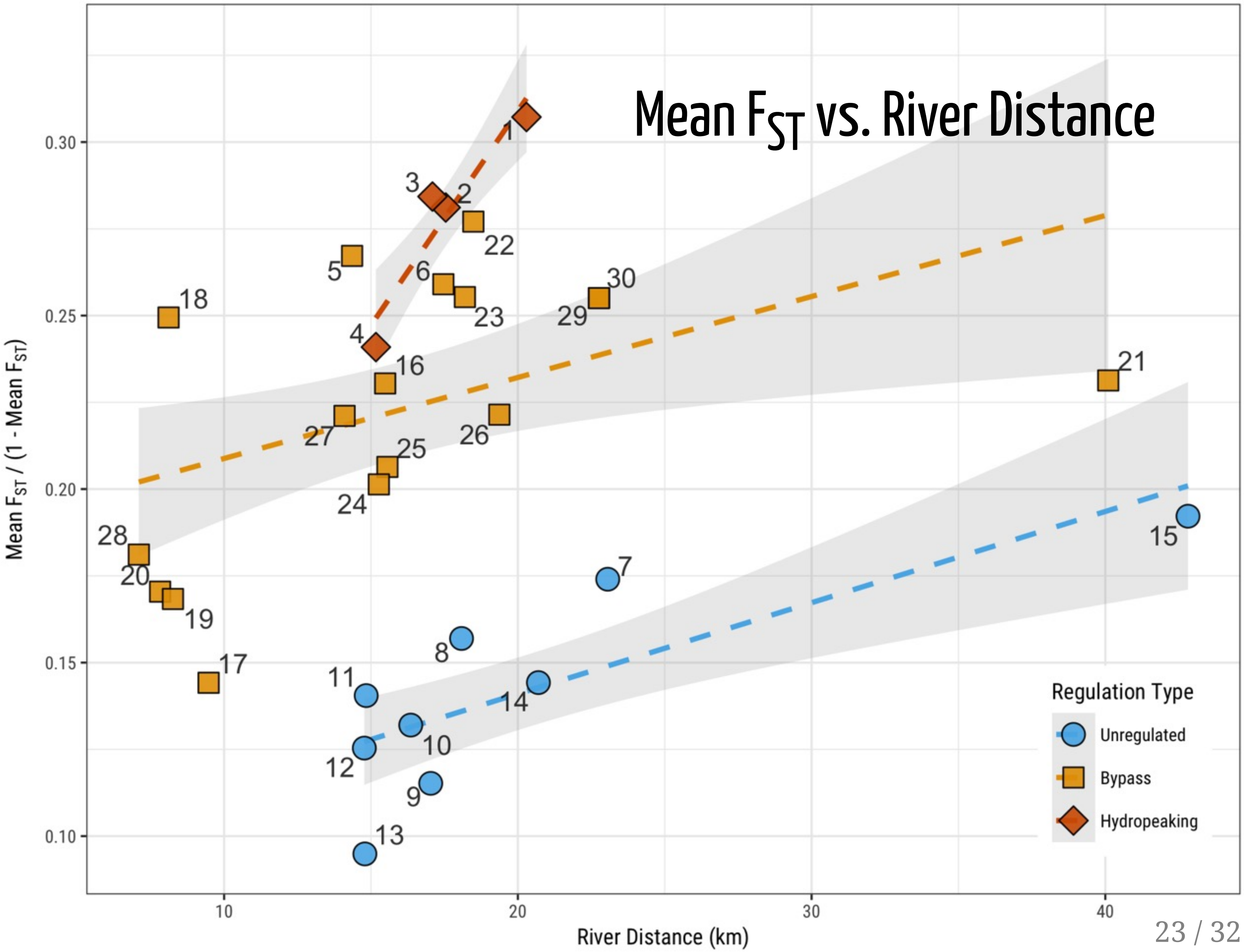

MFA RABO: 100k [PC1 (7%) / PC2 (3.63%)]
Hydropeaking sites in MF
American are strongly divergent
PC2
0.2
0.0
-0.2
-0.1
0.0
0.1
PC1
Site
1
2
3
4
5
6
Regulation Type
Bypass
Hydropeaking

Assessing Population Connectivity using F_{ST} (Wright 1950):

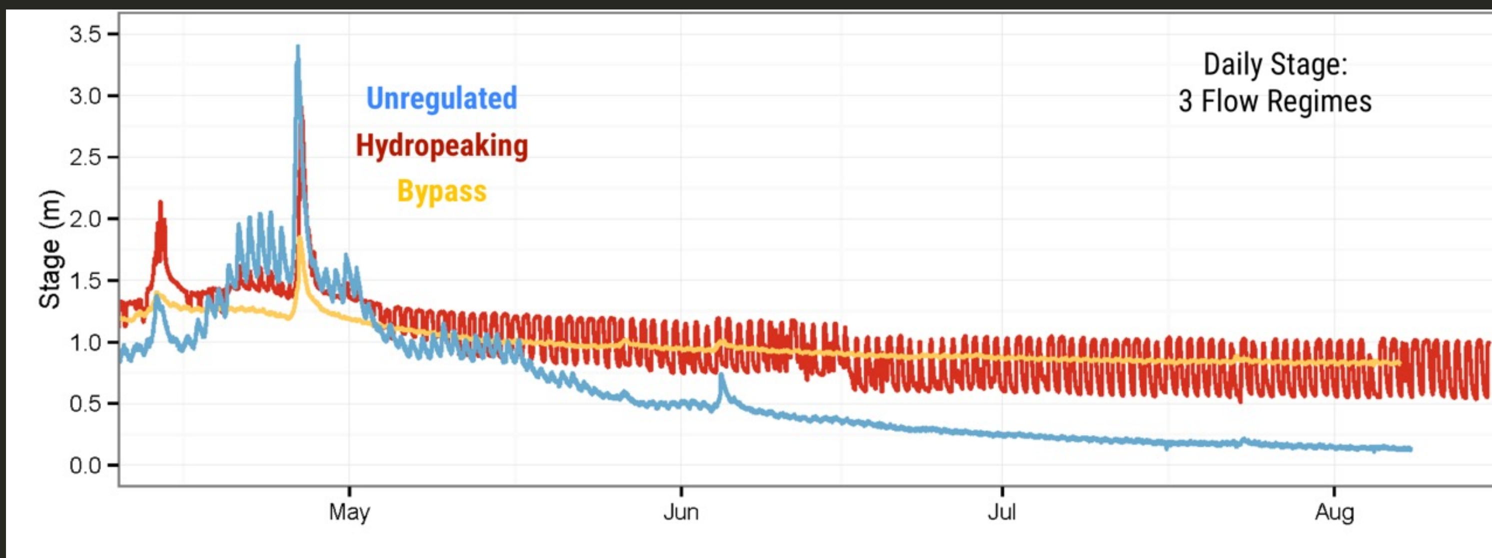
a measure of population differentiation due to genetic structure

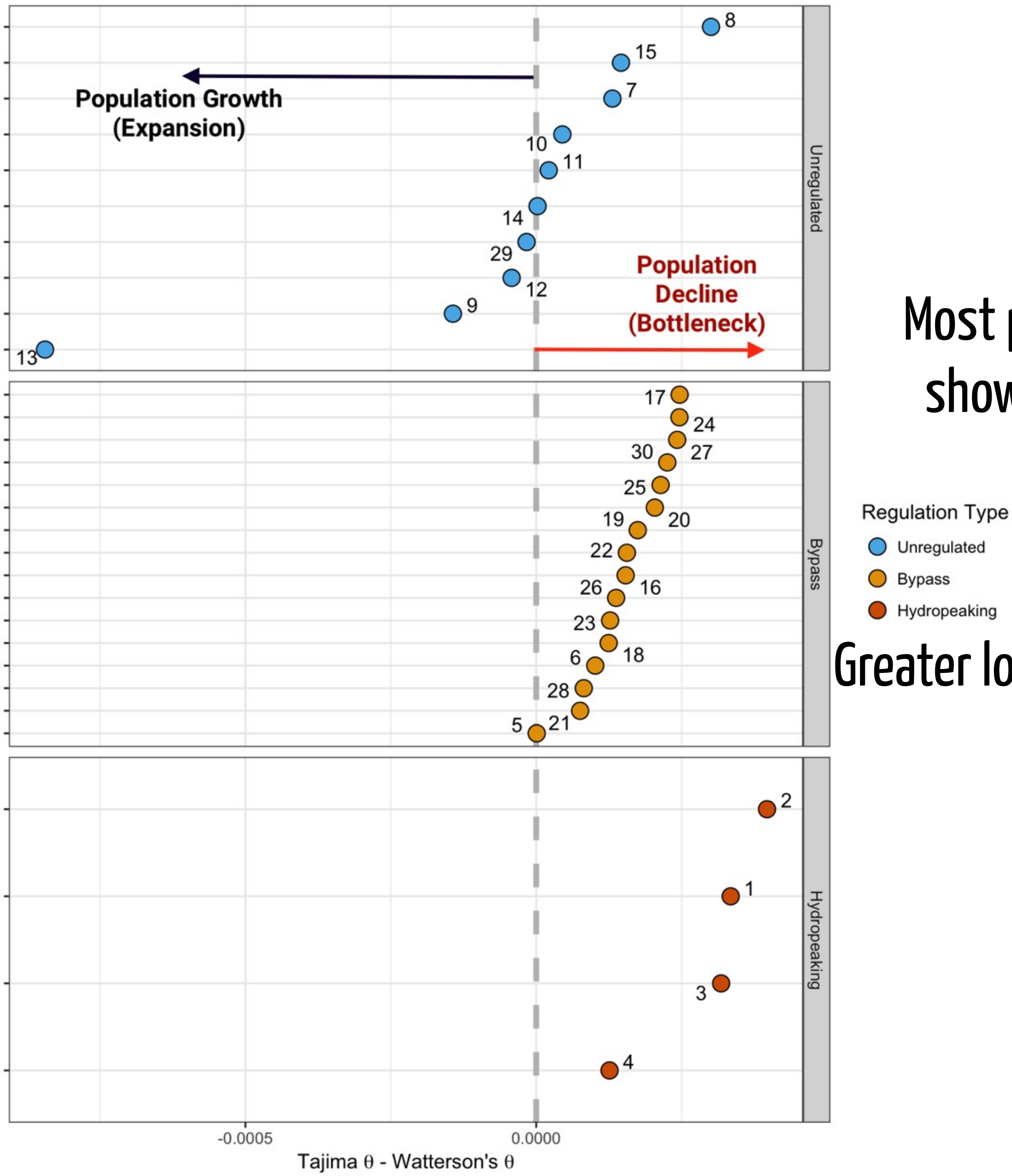
- Scaled 0=(panmixis) to 1=(completely different)

Mean F_{ST} vs. River Distance



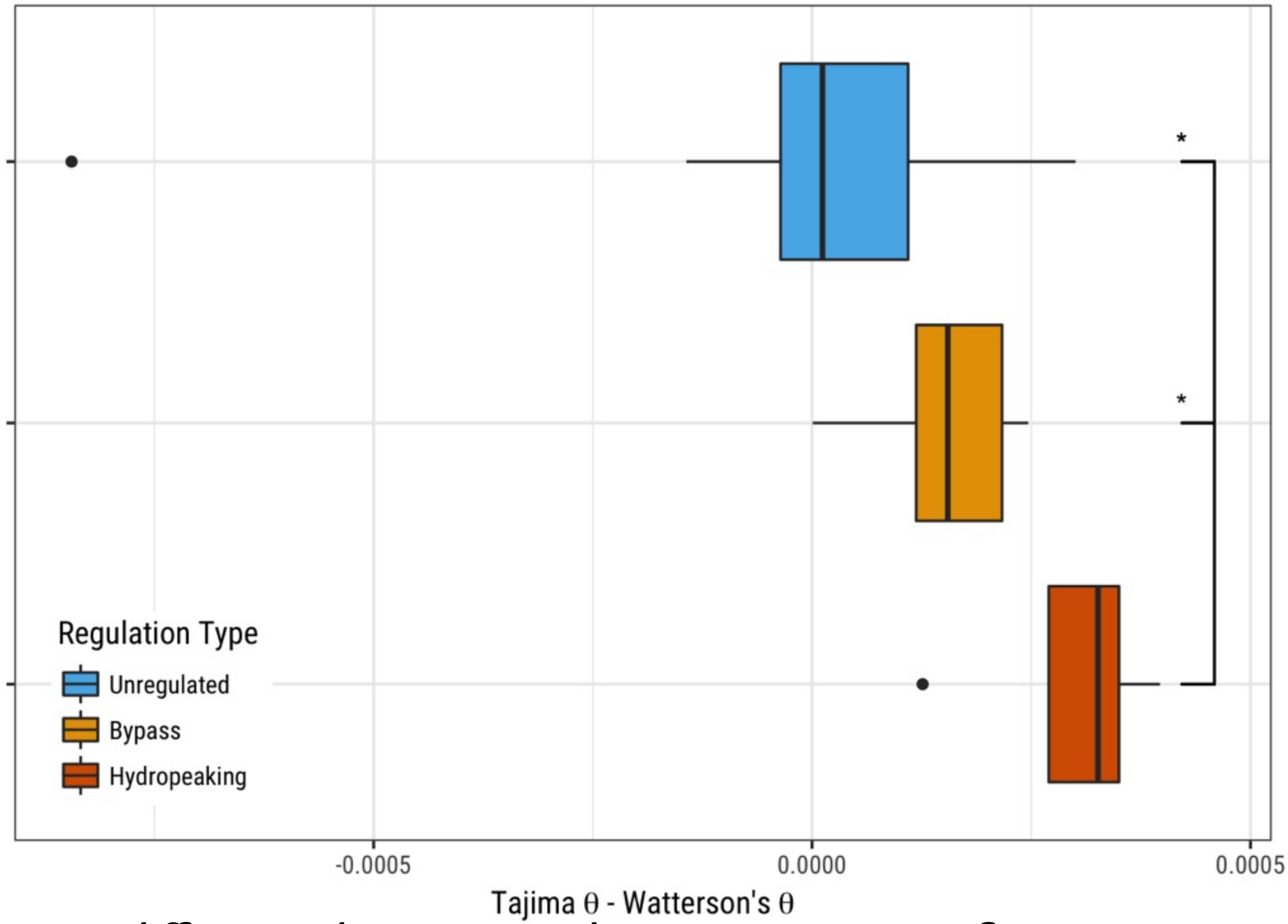
Evidence of Bottlenecks/Limited Genetic Variation for Impaired Flow Types





Most populations in N Sierra show pattern of bottleneck

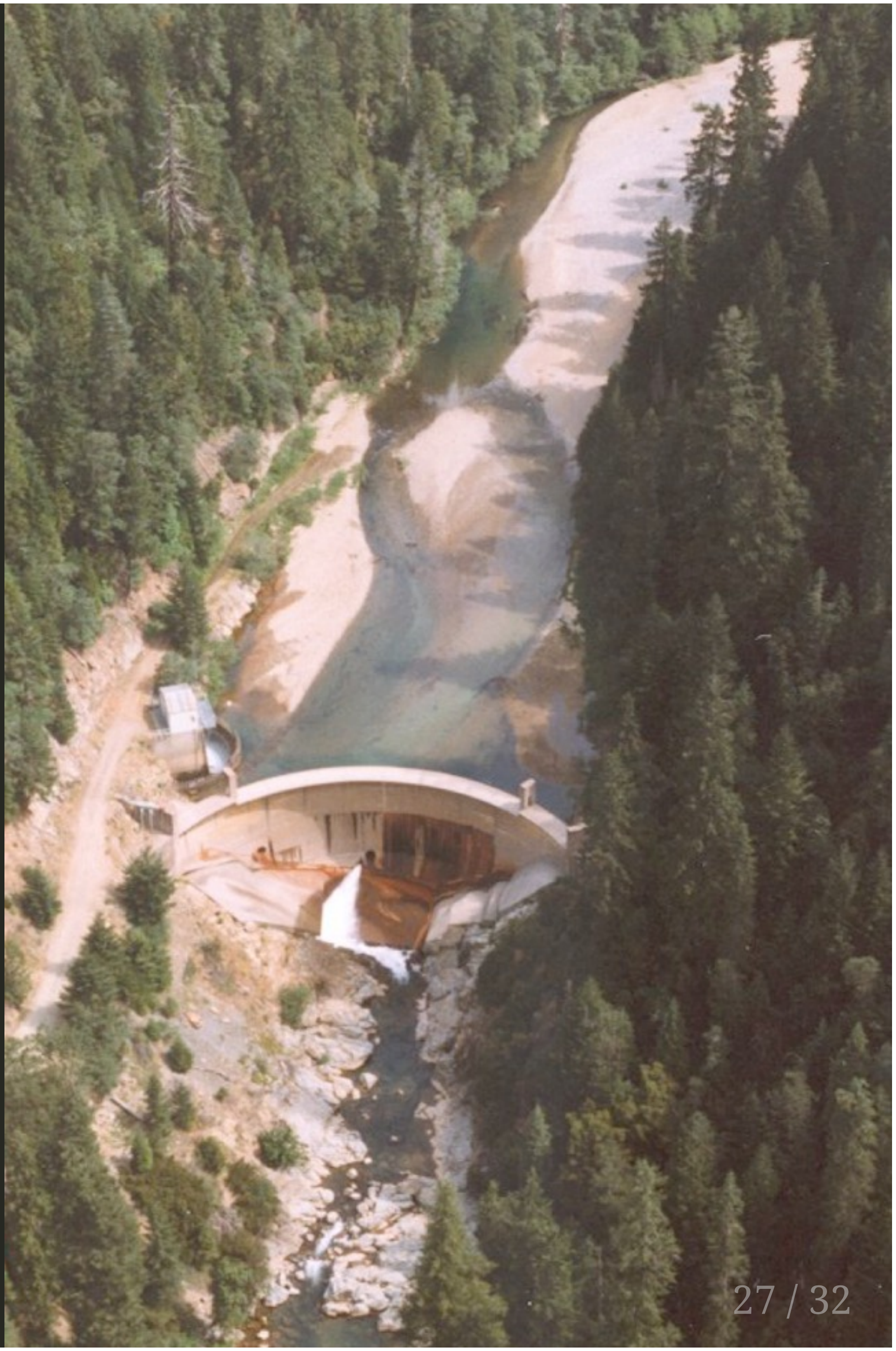
Greater loss of genetic diversity in regulated systems

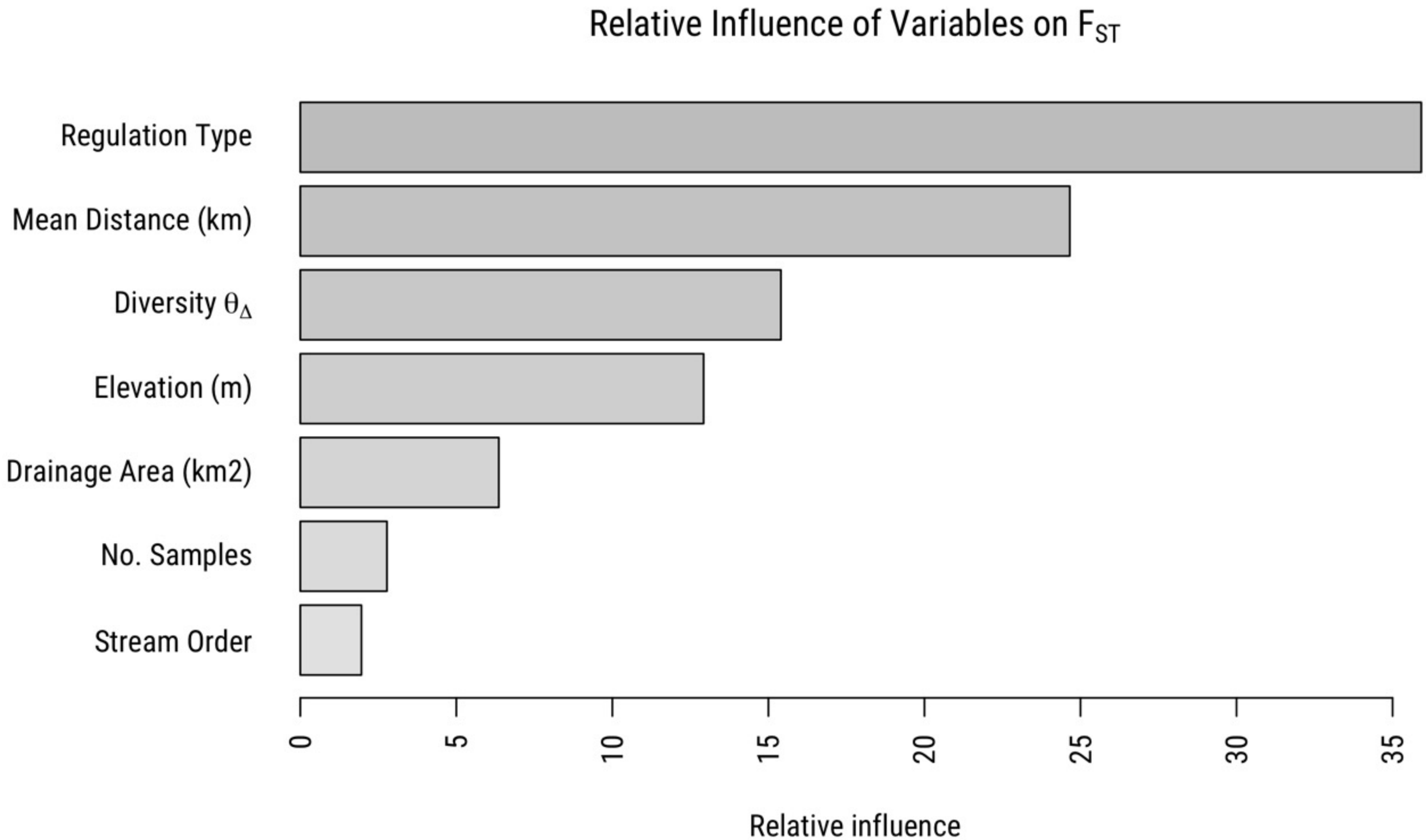


Genetic differences between regulation types are significant.

Wilcoxon rank-sum: bonferroni p<0.01

River regulation is the strongest predictor of population isolation, NOT distance!





Boosted Regression Tree Models

Summary:

Flow alteration is having a direct impact on a hydrologically sensitive species at a genomic level

The current population trajectory is highly concerning in Sierras

Flow management and listing distinct population segments may afford some protection...

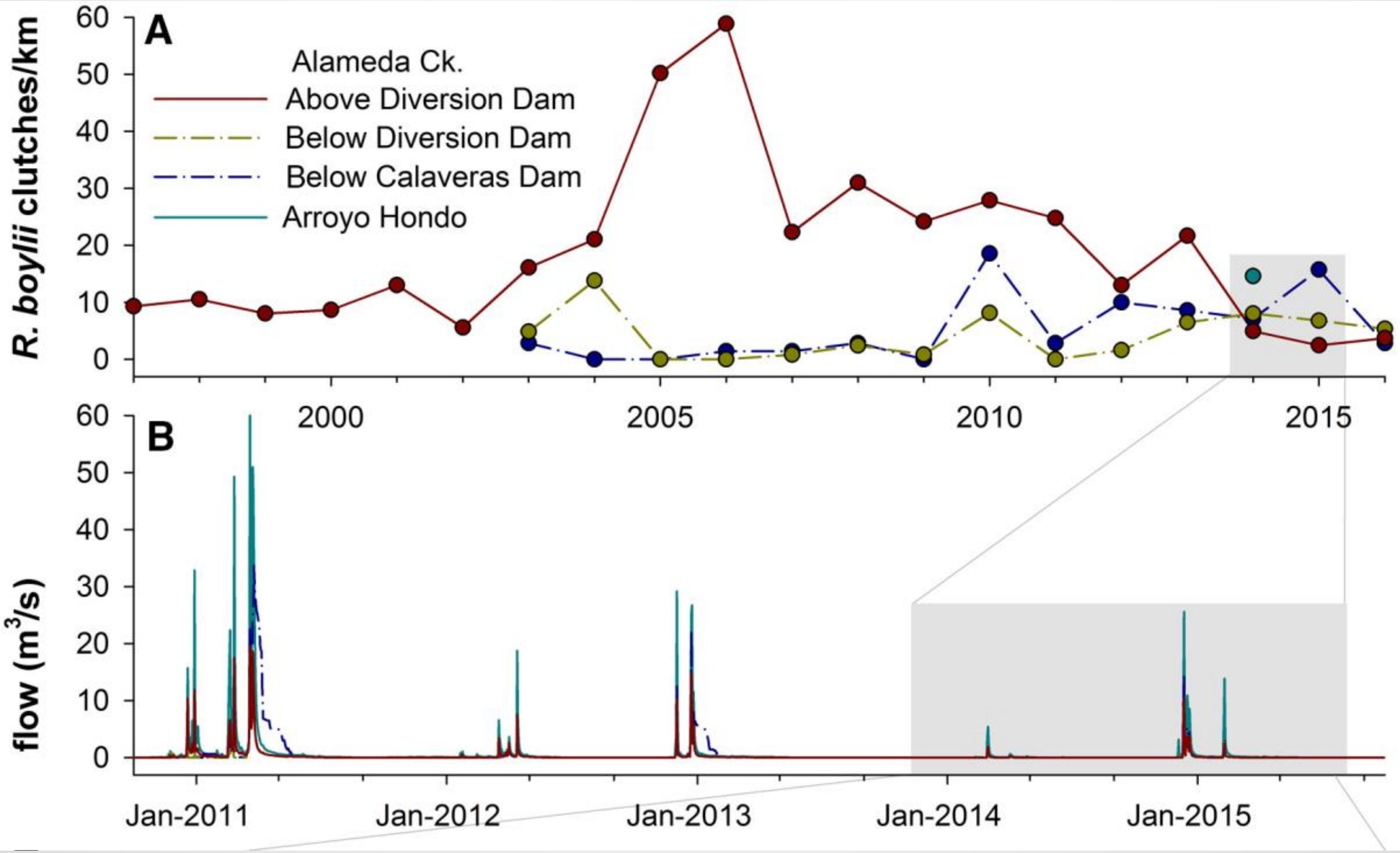
RAPTURE/RADSeq is a powerful & effective method


Thank you!
Slides : ryanpeek.github.io/presentations

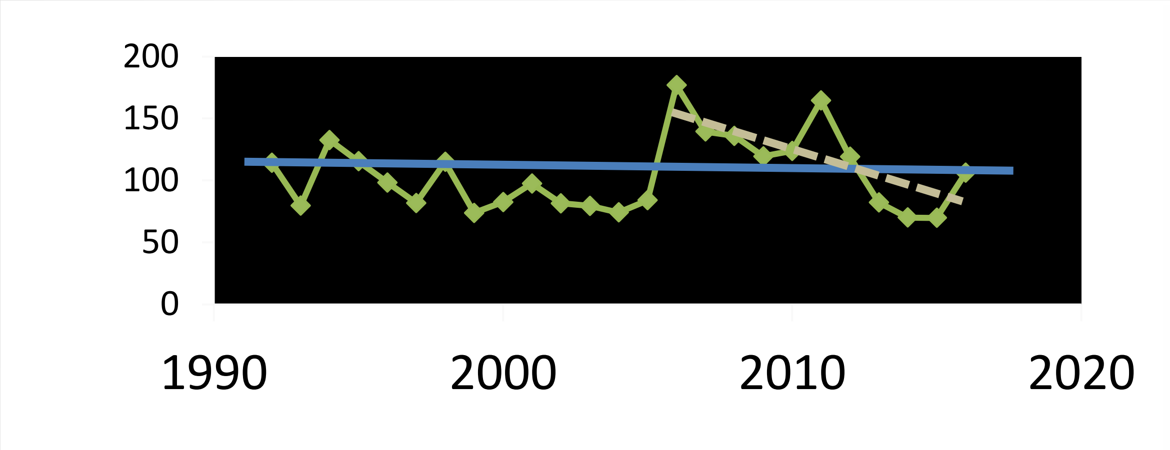
Rana boylii

- Natural History
- Breeding Timing & Plasticity
- Ecology
- Conservation Genetics
- **Population Dynamics**

Dynamics = Change over time



Trend detection depends on time frame



- 1 yr autocorrelation

- At SF Eel
  - Main driver of inter-annual variation appears to be recruitment success, with 3 yr lag

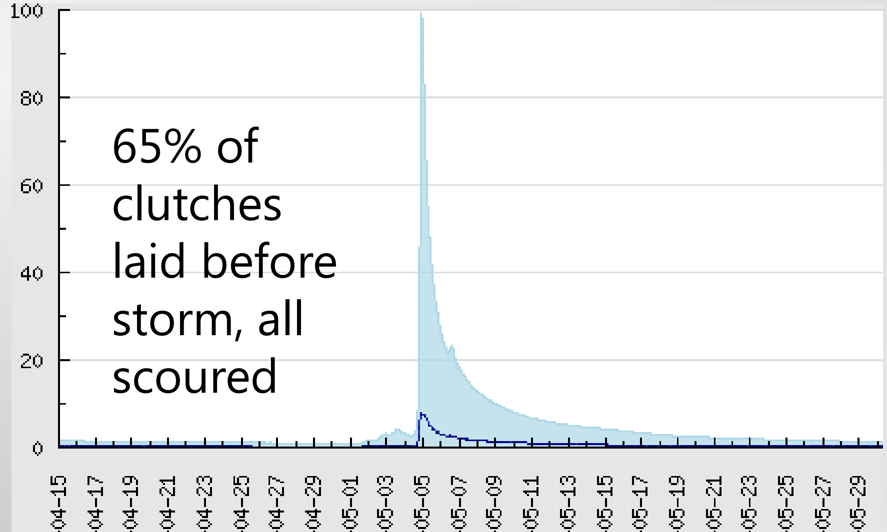
  - Declining over last decade

Several low recruitment yrs

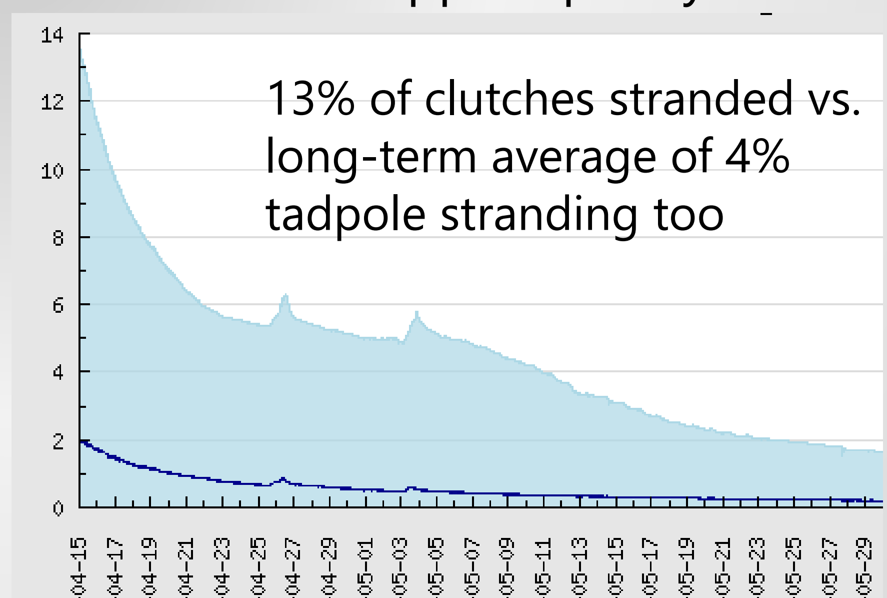
- 2006, 2008, 2014:

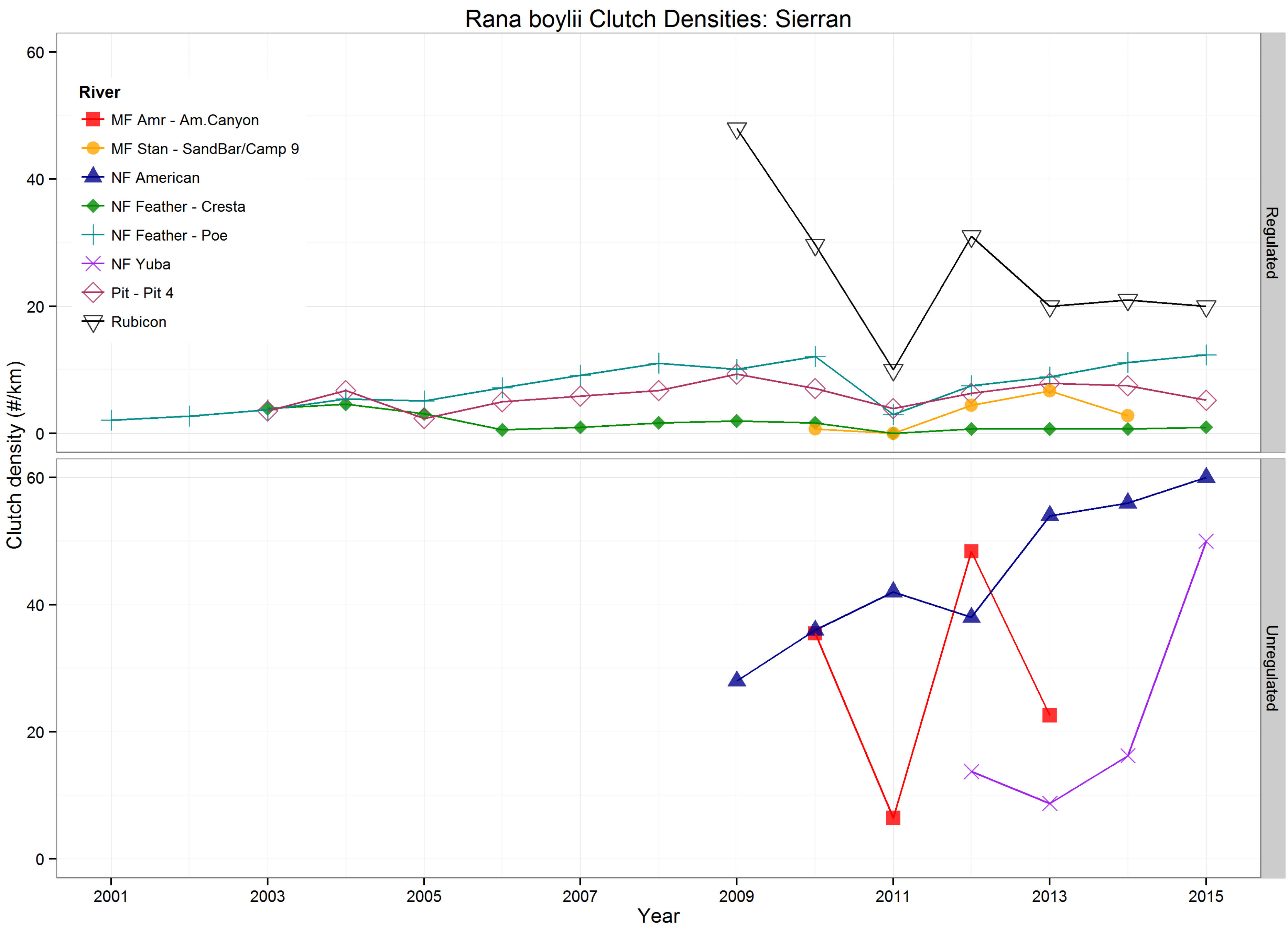
  high summer water temperatures
  low flows
  copepod parasites, mortality
  decreased metamorph body size

- 2009 & 2010: late rains

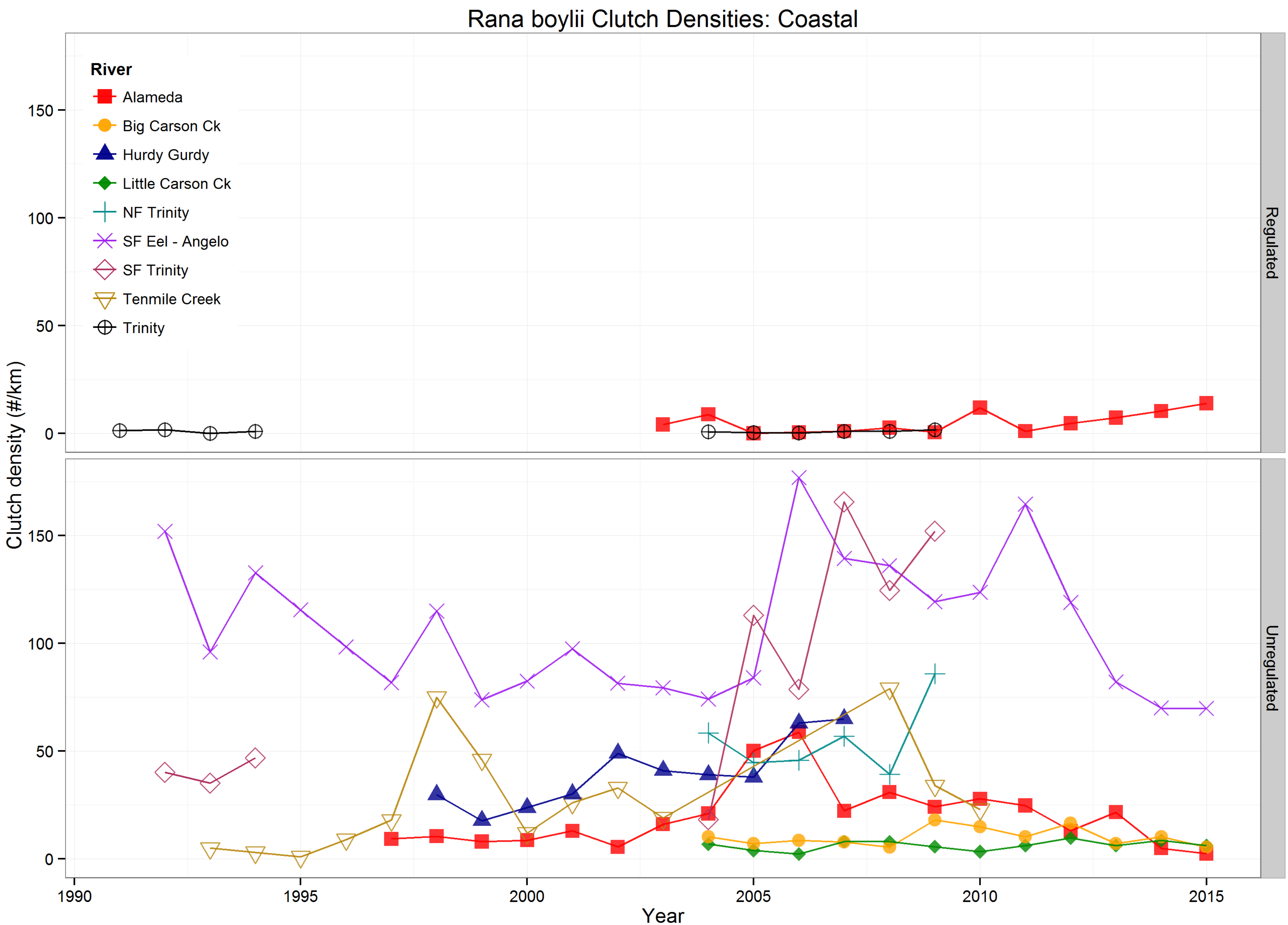


- 2012: flow dropped quickly



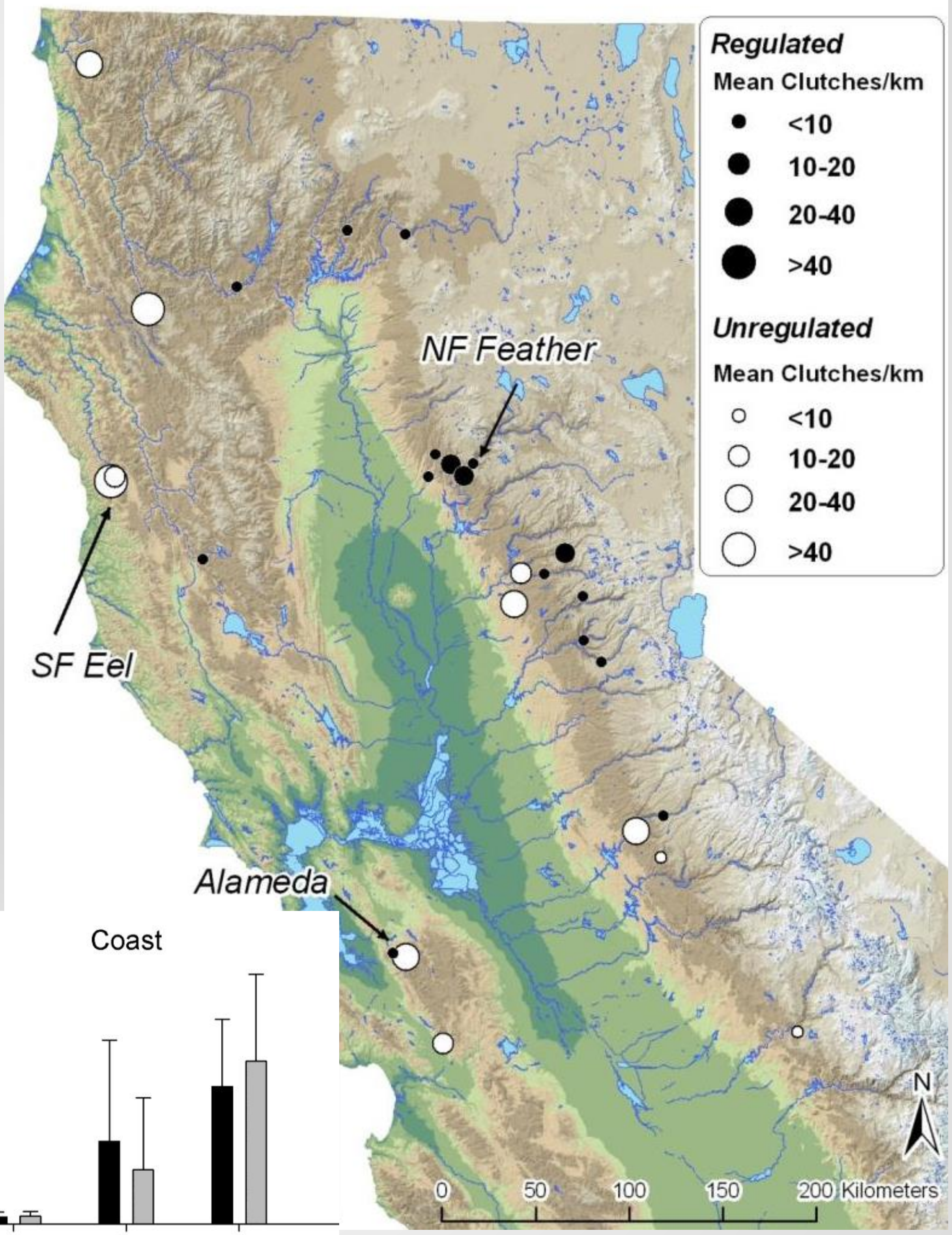


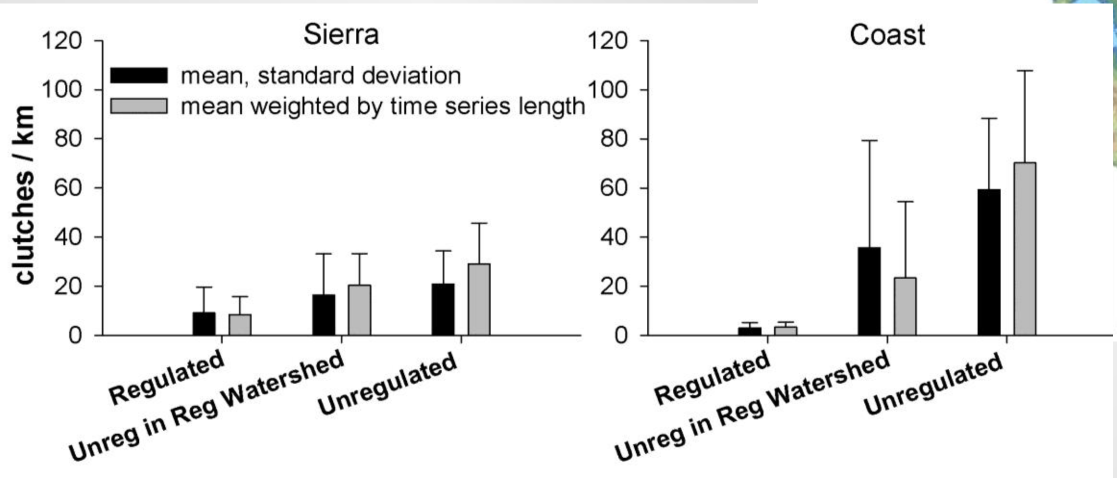
Rana boylii Clutch Densities: Sierran
River
MF Amr - Am.Canyon
MF Stan - SandBar/Camp 9
NF American
NF Feather - Cresta
NF Feather - Poe
NF Yuba
Pit - Pit 4
Rubicon
Regulated
Unregulated
Clutch density (#/km)
Year
0
20
40
60
2001
2003
2005
2007
2009
2011
2013
2015



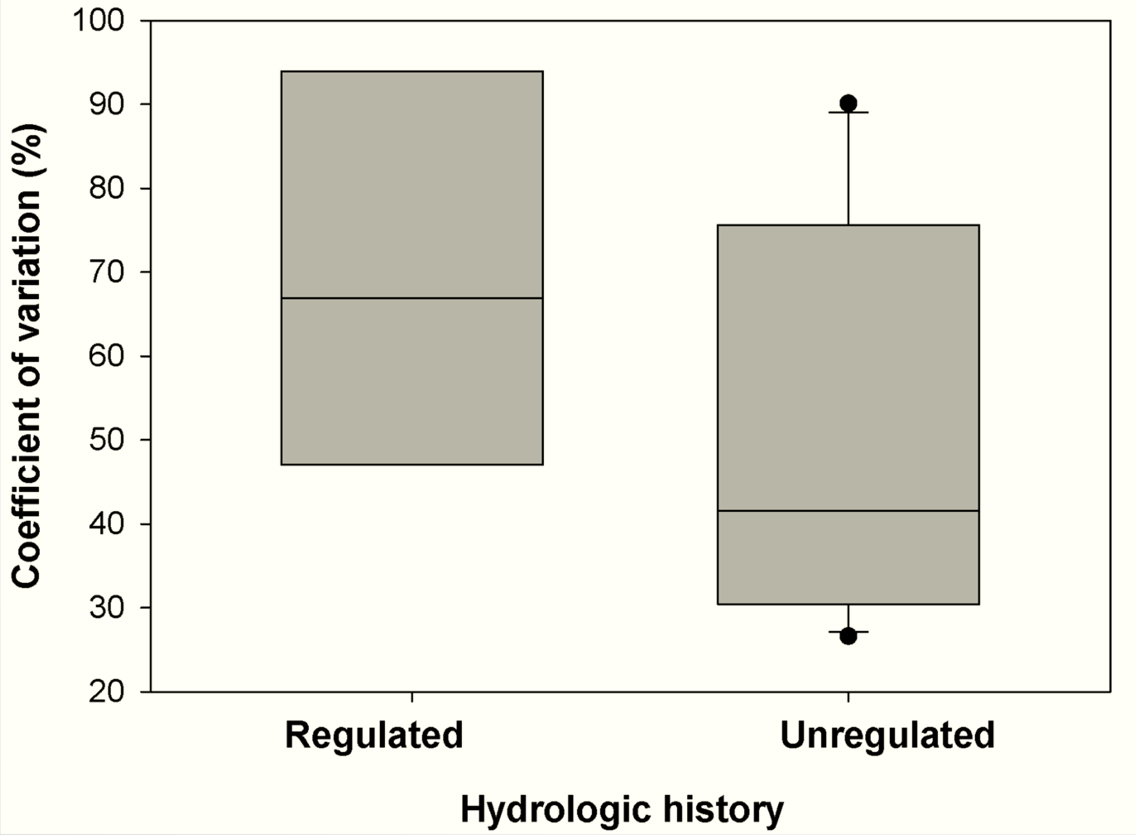
Rana boylii Clutch Densities: Coastal
River
Alameda
Big Carson Ck
Hurdy Gurdy
Little Carson Ck
NF Trinity
SF Eel - Angelo
SF Trinity
Tenmile Creek
Trinity
Regulated
Unregulated
Clutch density (#/km)
0
50
100
150
Year
1990
1995
2000
2005
2010
2015

Unregulated benchmark populations much larger than those in regulated rivers





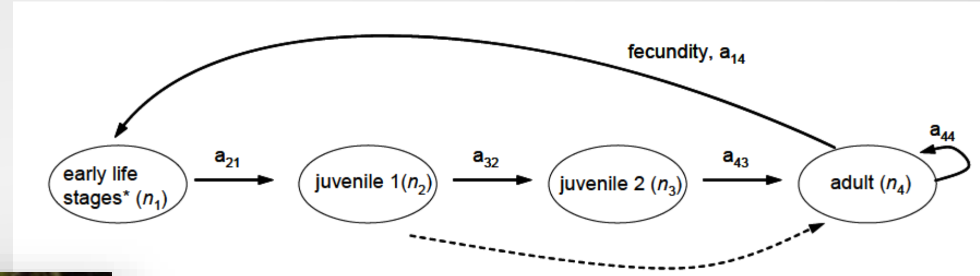
Absence of consistent trend ≠ stability



When high volatility combines with small population sizes

trends may not be detected until populations decline below critical thresholds

Field observations of survival rates and numbers of individuals used to build a model



FROM CLASS
(j's)

Northern California

N_{t+1}= TO CLASS (i's)

$$N_{t+1} = \begin{bmatrix} 0 & 0 & 0 & a_{14} \\ a_{21} & 0 & 0 & 0 \\ 0 & a_{32} & 0 & 0 \\ 0 & 0 & a_{43} & a_{44} \end{bmatrix} \times \underbrace{\begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \end{bmatrix}}_{N_t}$$

matrix of transition probabilities   population vector

Central California

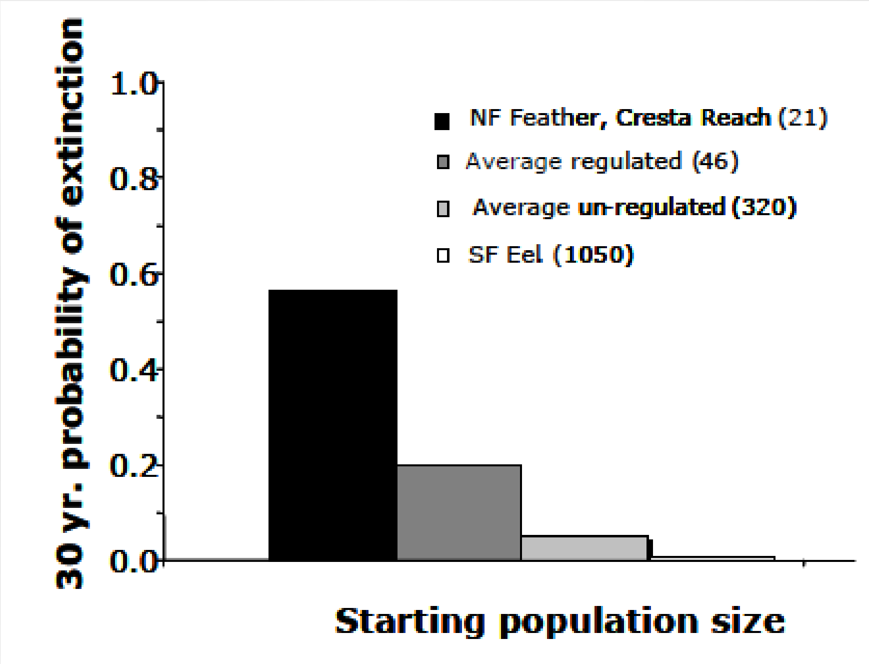
$$N_{t+1} = \begin{bmatrix} 0 & 0 & a_{13} \\ a_{21} & 0 & 0 \\ 0 & a_{32} & a_{33} \end{bmatrix} \times \begin{bmatrix} n_1 \\ n_2 \\ n_3 \end{bmatrix}$$

Population viability analysis

- Evaluate extent of risk due to small pop. size

- Plastic age to sexual maturity

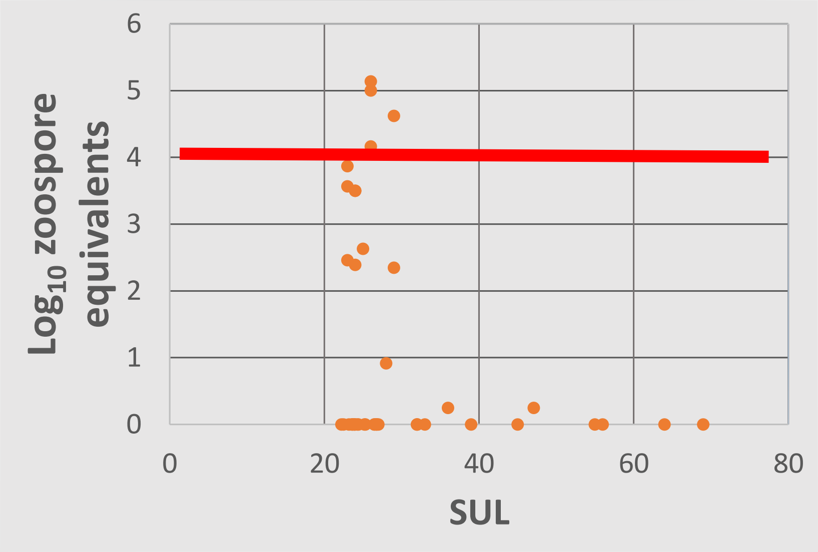
(Kupferberg, Palen, Lind 2009)



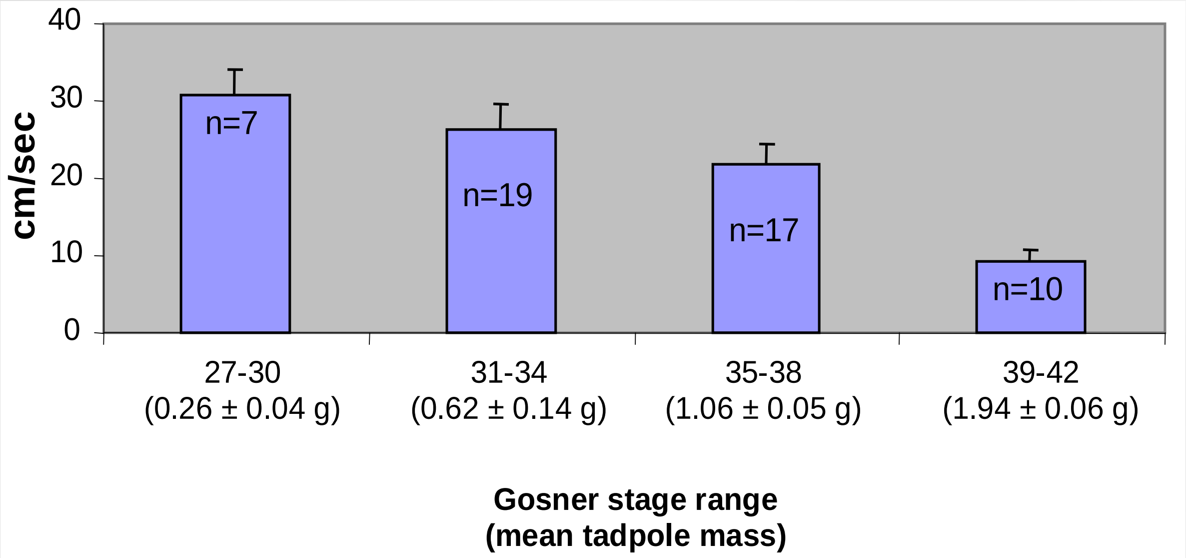
Scenario	30-yr extinction probability	Multiplicative change in probability of extinction[1]
3 yr to maturity	0.05	-
2 yr, warmer temperature, ample resources	0.02	-2.5

Virtual Experiments

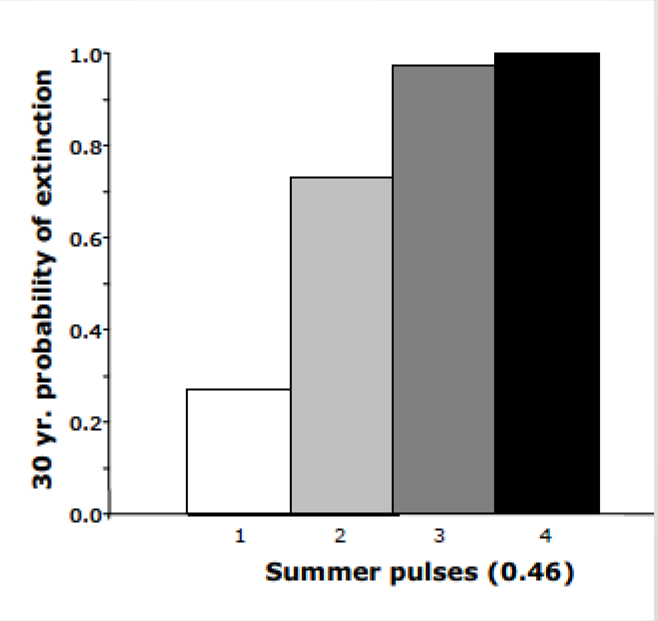
- Change transition probabilities based on a known threat
- project effect forward 30 yrs
- e.g. decrease juvenile survival bcs of Bd



Simulate effects of pulsed flows



From small scale swimming experiments to population level impact



Small, Fragmented Populations
face
Multiple Threats

- Altered flow, temperature, sediment transport
- Vegetation encroachment, channel incision
- Invasive species
- Parasites and disease
- Cannabis cultivation

Opportunities for restoration

No lake since 2007

Frogs colonized gravel bars

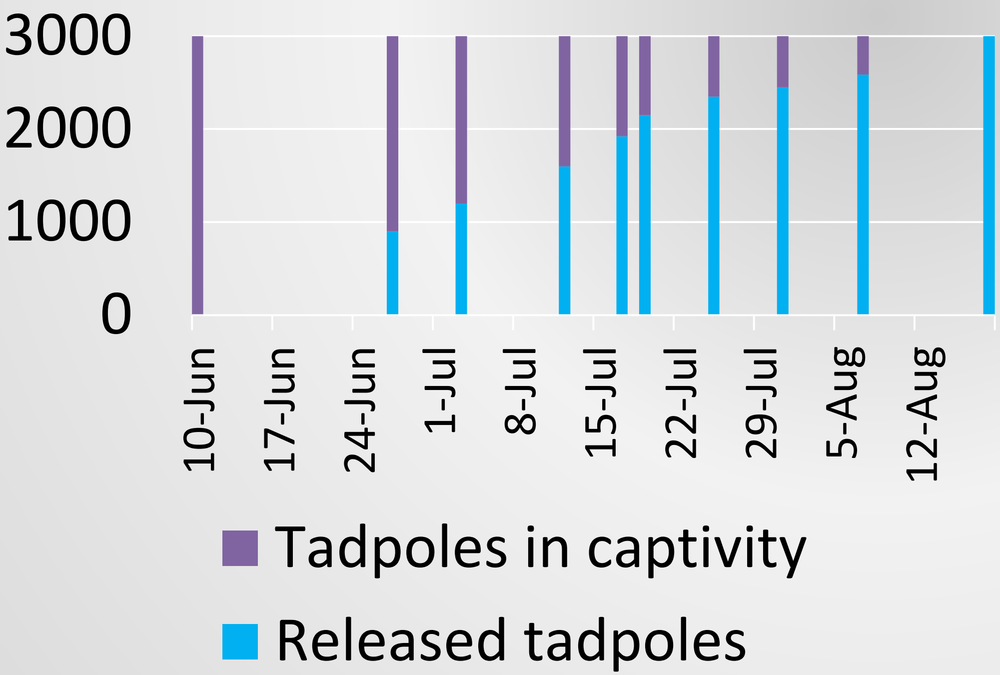
- In 2016, 2017 rescue and relocation during dam removal

Opportunities for Recovery

- Cresta Reach of N. Fk. Feather
- PG&E license required recreational white-water boating releases
- Surveyed by Garcia and Associates (2002-2017)
- Historically, > 30 egg masses / yr
- <u>Only 4 in 2016, 2 in 2017</u>
- Management changed, population not recovering
- Introduced predators – bass, crayfish

Head Starting

- Pilot project 2017
- Needed to rescue from stranding
- W/o intervention, 1-4% survival to metamorphosis
- With captive rearing, 13.6% of cohort released as metamorphs



Opportunities for Education

Barrier and signs erected by Marin Municipal Water District on Little Carson Creek

Photo credit: MMWD

Discussion

- Listing under CESA, ESA
- Distinct Population Segments?
- Forest Practices?
- Reintroduction to absent sites.

e.g. Yosemite? Southern Cal?

Contact:

- rapeek@ucdavis.edu
  - @riverpeek
- skupferberg@gmail.com

A. Catenazzi