A SENTINEL MONITORING NETWORK FOR DETECTING THE HYDROLOGIC EFFECTS OF CLIMATE CHANGE ON SIERRA NEVADA HEADWATER STREAM ECOSYSTEMS AND BIOLOGICAL INDICATORS

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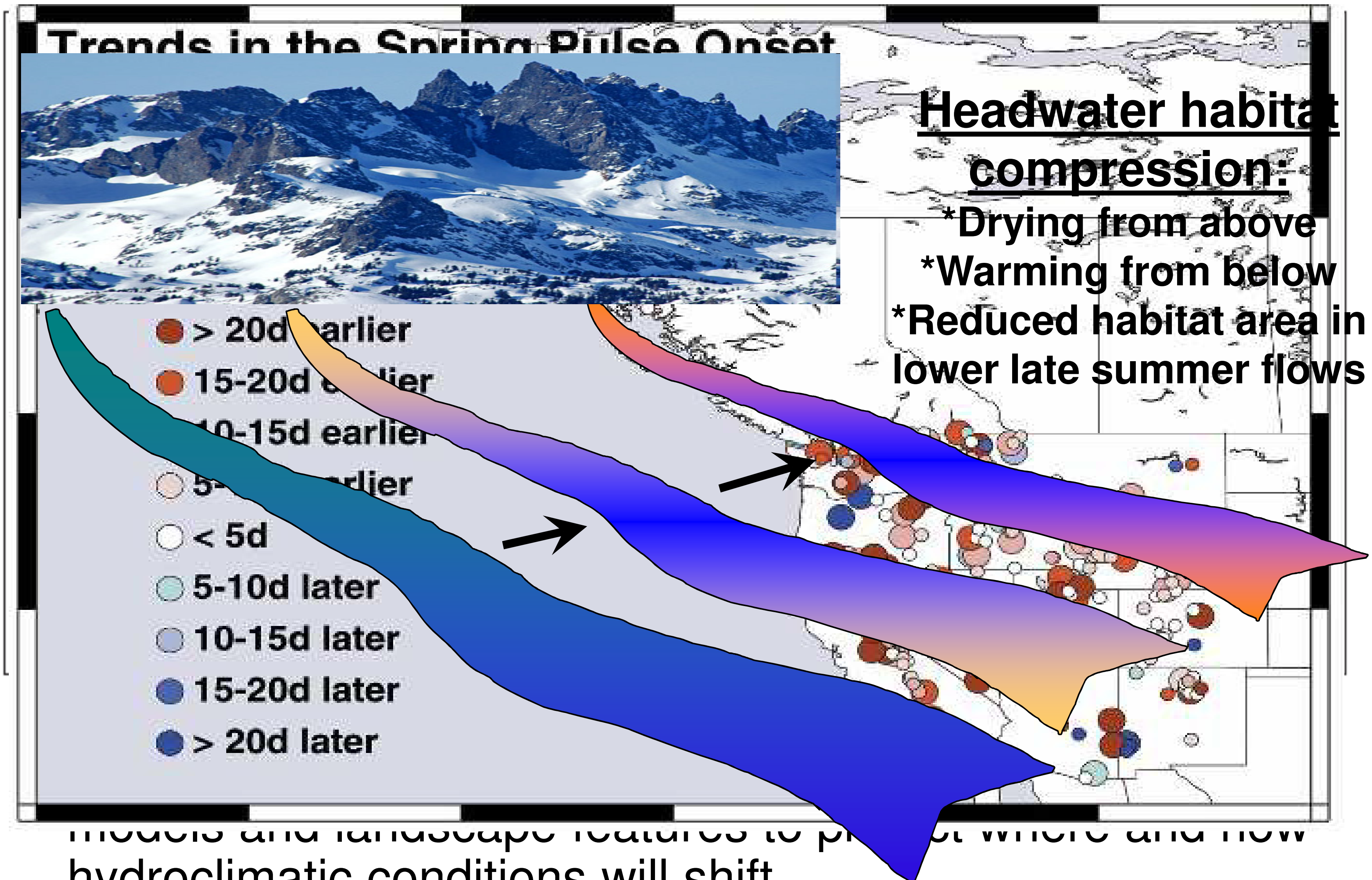
Outline Overview:

- **How does climate change influence mountain stream hydrology?**
- **Why is this important to bioassessment and conservation?**
- **Using models forecasting hydroclimatic risks vs habitat resistance features to design a monitoring network for the Sierra Nevada**
- **Preliminary results, insights to stressors, and applications of data set**

Motivations for study:

- **Forest Service mandate: advance and share knowledge about water and climate change, and how to protect and restore aquatic habitats *(Furniss et al. 2010. Water, Climate Change & Forests; USFS PNW-GTR-812)***
- **Provide a reference stream baseline of natural conditions to produce biological health standards for Management Indicator Species program in National Forests of the Sierra (across 7 National Forests)**
- **Evaluate the extent of reference decline or drift that might occur with effects of climate change, and use for calibration of CA-SWAMP biocriteria standards in the Sierra**
- **Integrate climate change in planning & assessment of forest management practices using BMIs for USFS R5**
- **Assist "Vital Signs" and "Inventory & Monitoring" programs of National Park Service (in 3 Sierra National Parks)**

Background



models and landscape features to pr[illegible]ct where and how
hydroclimatic conditions will shift

Regulatory Application of Study: Biological water quality assessment programs

- Programs depend on reference streams to serve as standards for assessing impaired biological integrity
- But what if reference stream conditions are not stable and change beyond natural levels of variation in location and time? Assessment becomes a moving target.

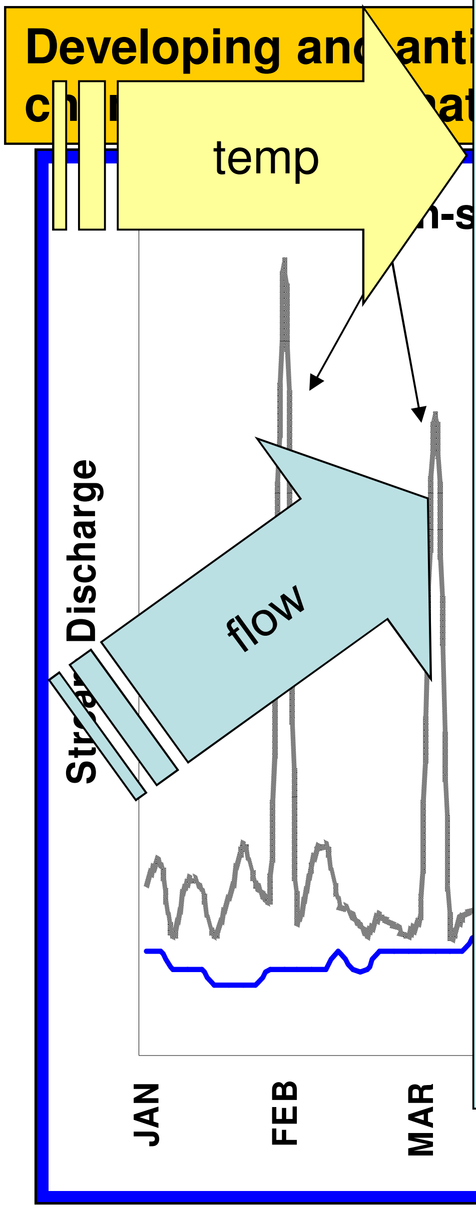
High quality reference sites have most to lose:

- If reference values degrade and become more variable, this increases the signal-to-noise ratio and loss in capability of reference condition to detect impairment
- Climate change may result in reference drift >degraded condition lowers the biological standard
- Need for re-calibration of bio-objectives / standards

A Changing Hydrograph:

Shift in the mountain snowmelt flow regime

Developing and anti… ch… mat…



<u>Biological responses</u>* *of native benthic invertebrates <u>to</u>
***<u>warming and altered flow regime</u>*:**

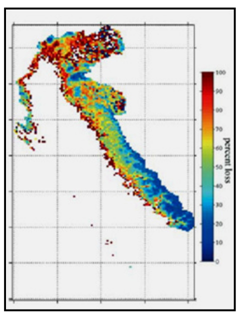
- **Life history/phenology: >favors shorter generations, & loss of long-lived taxa**
  - **>more *generalist,* fewer *specialist* traits**
  - **>shift to common, widespread taxa**
- **Migration: >movement into headwater refugia?**
- **Abundance: >warming increases growth for some but others cannot survive warming >habitat areas diminished under low summer flows (lost from food chain)**
- **Physiological stress: >loss of sensitive species**
- **Emigration escape: >drift in currents or flight**
- **Dormancy: >hunker-down (resistant stages)**
- **Shift from a perennial stream community to an intermittent type (fewer, seasonal-adapted taxa)**
- **Local extirpation of species**

D E S I G N

3rd-order size watersheds of Sierra Nevada

Reference selection filter using GIS: mininimum roadedness or land use, no reservoirs, all above 1000 m)

Reference 3rd-order watersheds (local impacts minimal to none)



Climate forecast filter: VIC-hydrological model prediction of snowpack and stream flow

Ranked list of watersheds by quartiles of lowest and highest **climate risk**

Natural Resistance Filters: rank low to high

- Northness Aspect (snowmelt timing, temp, vegetation)
- Groundwater contributions (geology/springs)
- Riparian cover and meadow area (water storage)

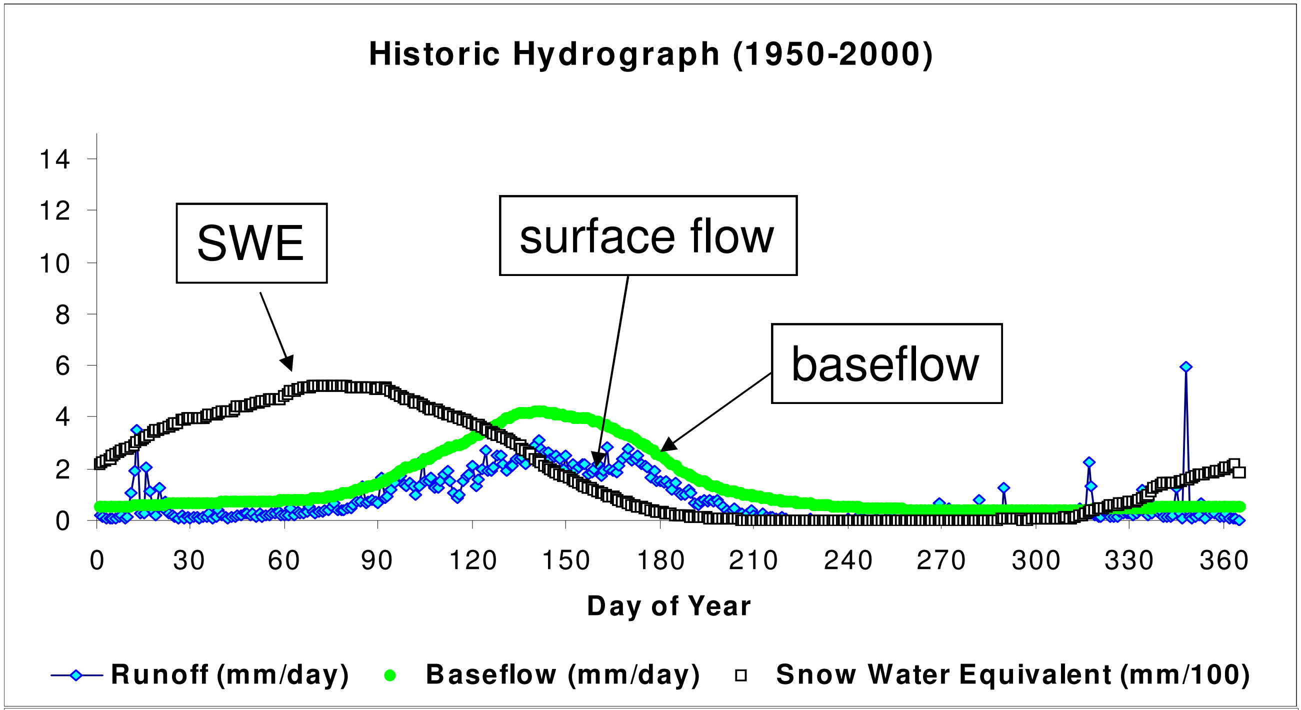
field reconnaissance of best candidate sites

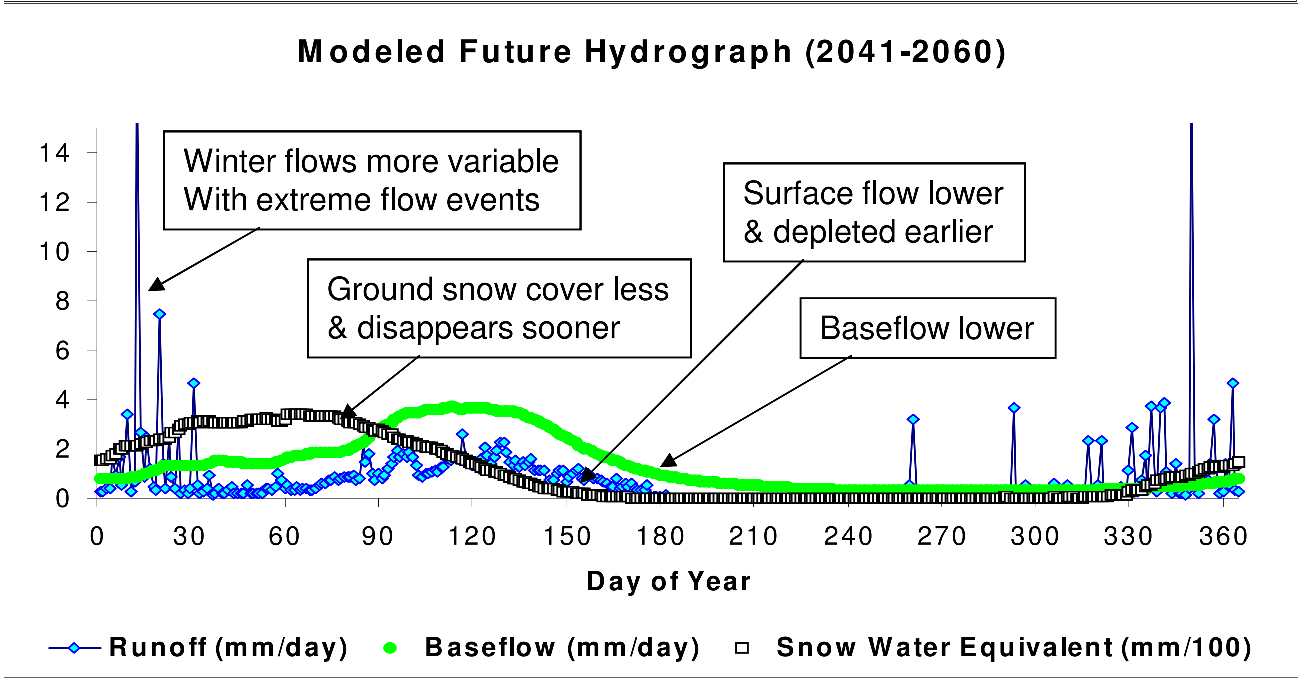
Low Risk High Resistance	**High Risk High Resistance**
Low Risk Low Resistance	**High Risk Low Resistance**

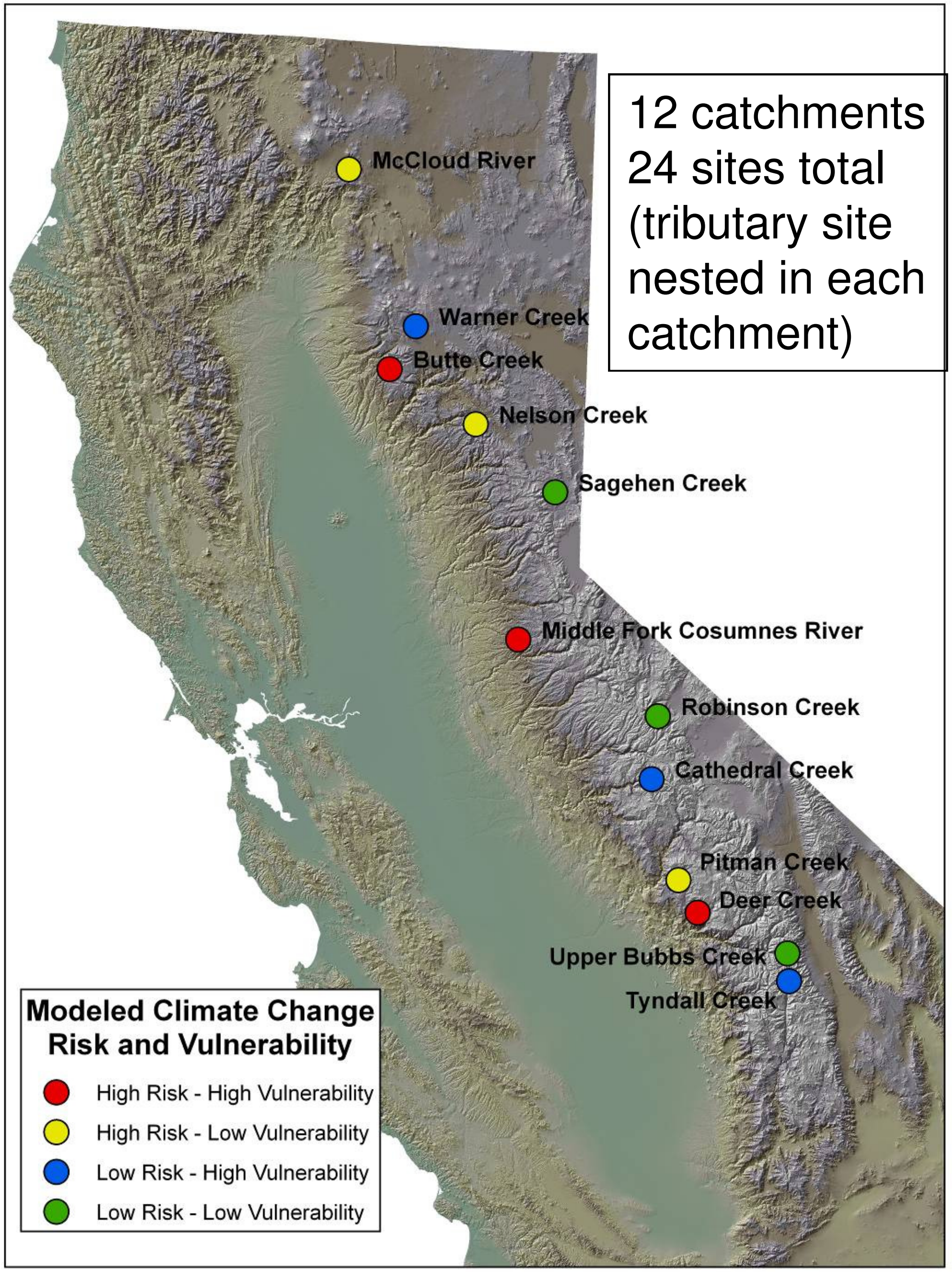
3 watersheds each category with differing exposures and expectations for the influence of climate change

Designed as a **natural experiment**

VIC model Output: Use Forecast Change as Risk Level







Sentinel Monitoring Network for Sierra Nevada

Selections based on summed **Climate-Risk factors** from VIC:
- Reduction in April 1 SWE
- Change in total AMJ run-off
- Change in total AMJ base-flow

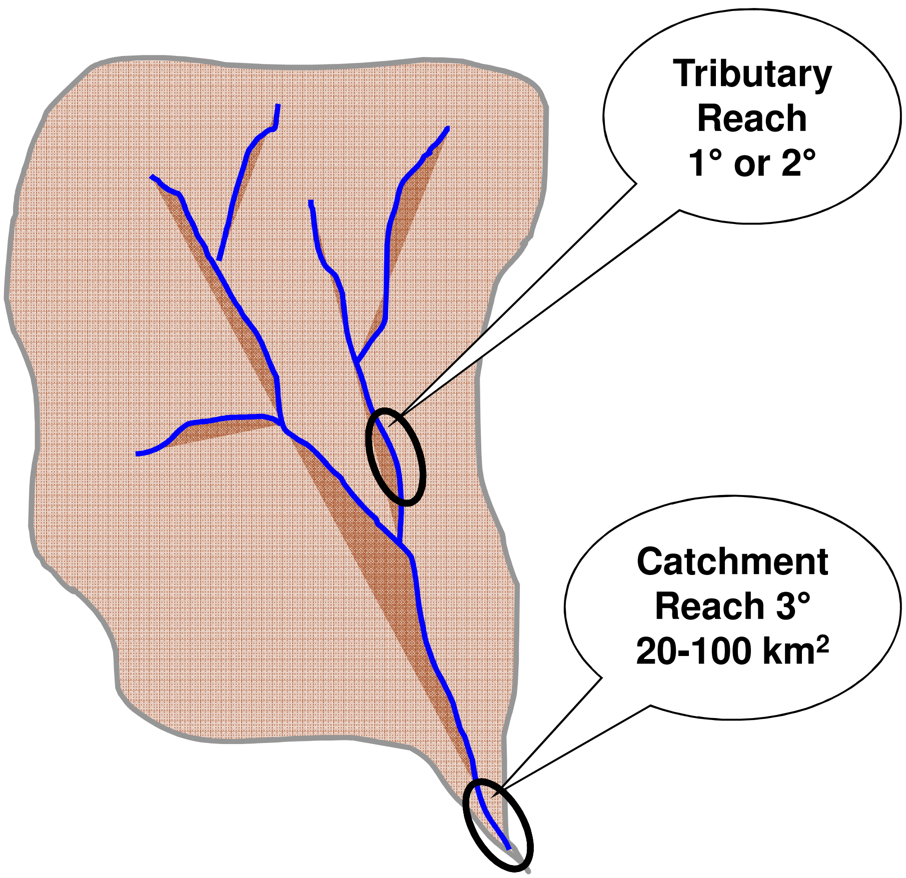
upper quartile of change =high risk
lower quartile of change =low risk

Natural Resistance:
upper / lower quartiles for
North-facing = low vulnerability
South-facing = high vulnerability
Plus, resistance conferred by deep groundwater-recharge potential from basalt / andesite geology area (Tague and others 2008)

17 in 7 National Forests
7 sites in 3 National Parks

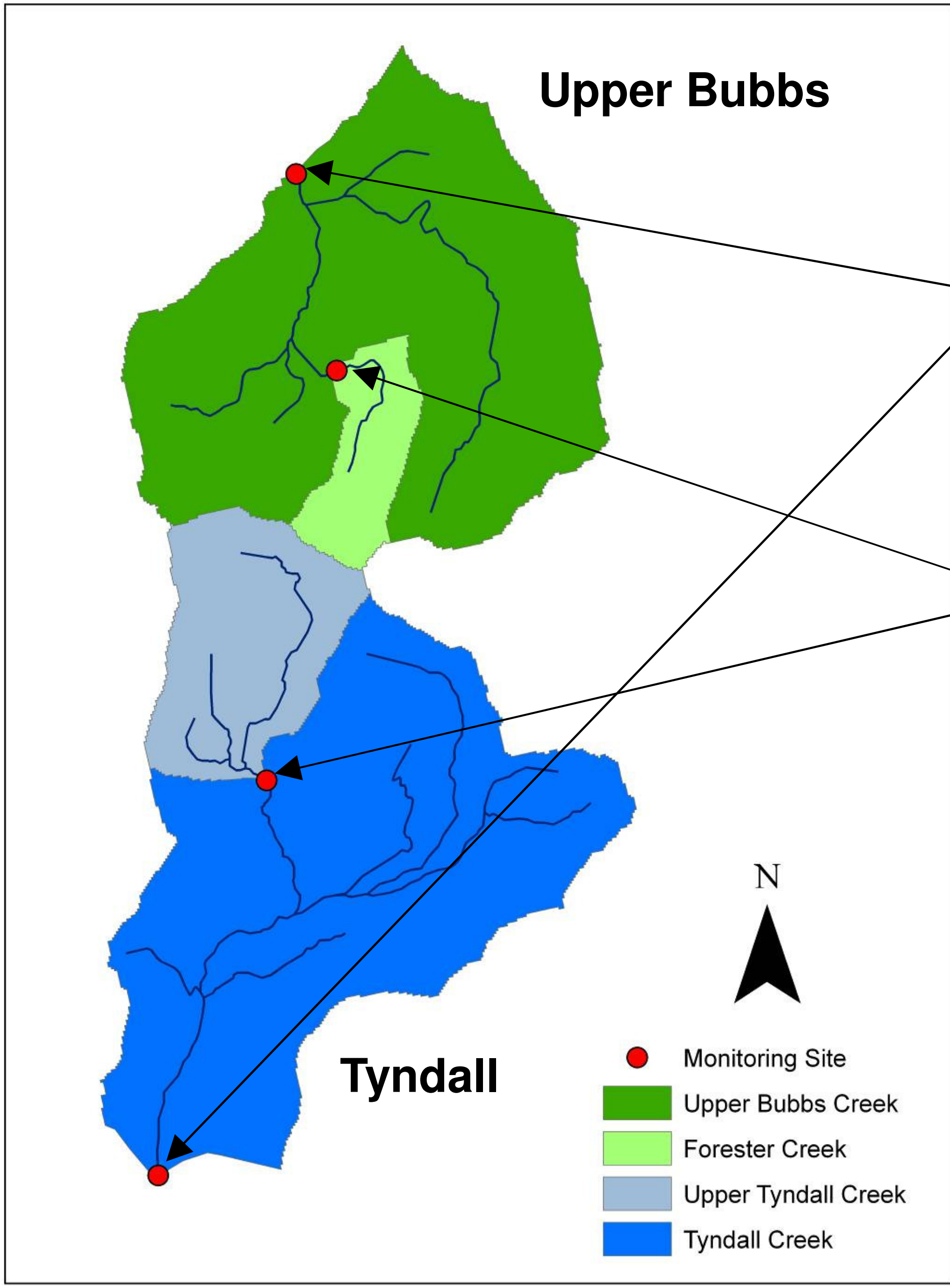
Nested Tributaries

12 catchments + tributary in each: 24 stream reaches total network



Monitoring Protocols: SWAMP-based

<u>Survey Monitoring data collected</u>:
- 150-m reach length
- channel geomorphology including bankfull cross-sections (substrata-depth-current profiles, embeddedness, slopes, bank and riparian cover, riffle-pool ratio, etc)
- conductivity, alkalinity, SiO_2, pH
- large woody debris inventory
- cobble periphyton (Chl <u>a</u>, taxa IDs)
- CPOM & FPOM resources
- macroinvertebrates (RWB & TRC)
- adult aquatic insect sweeps
- photo-points



Instrumentation set up at monitoring stations:

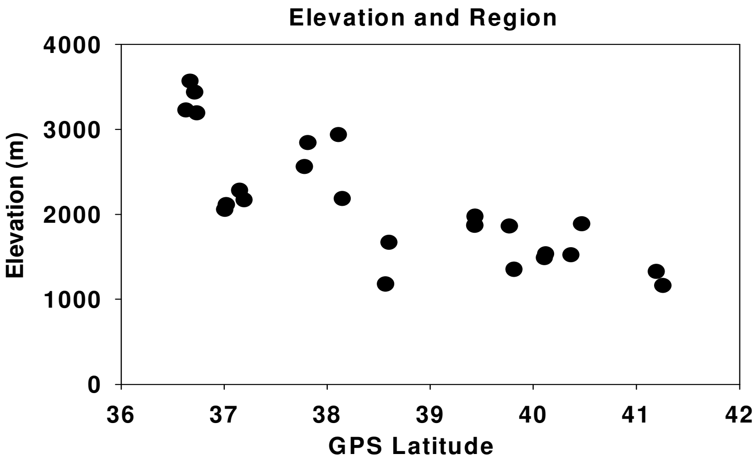
Stage-level pressure transducers and Temperature probes at catchment reaches (water and air)

40 min recording intervals

Temperature probes at tributary reaches

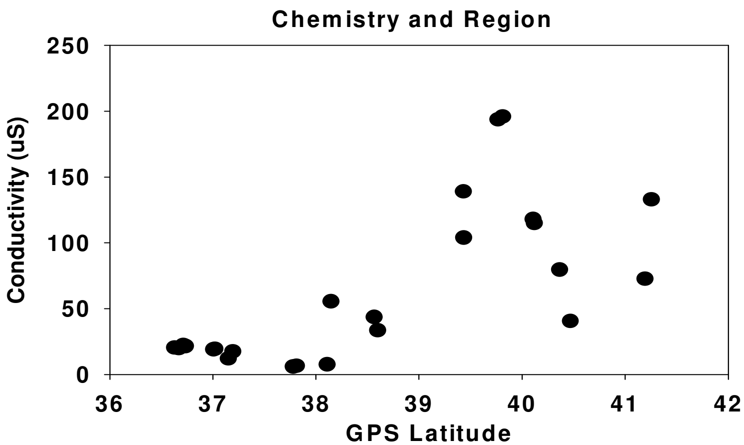
not enough $ to put pressure transducers in tributaries

GIS Analysis at each:
land use, roads, geology, riparian, meadow & forest cover, cool-air pooling algorithm, groundwater recharge

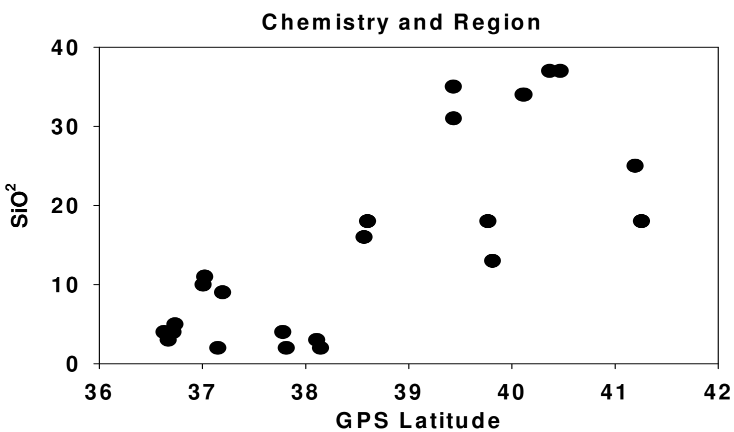


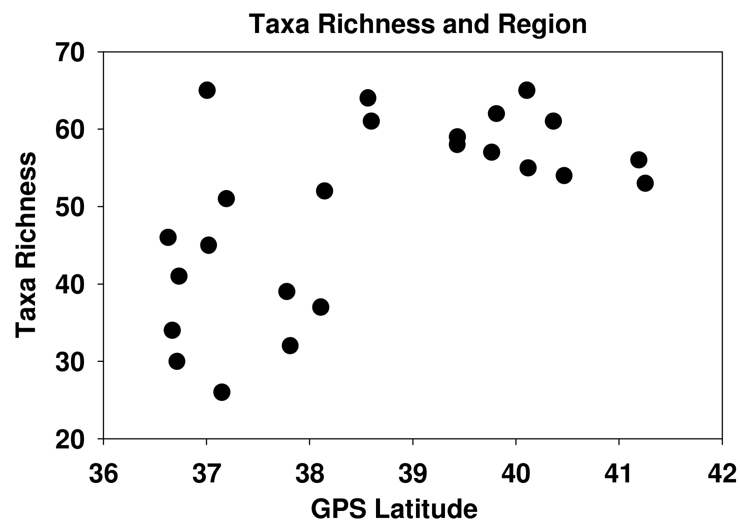
Streams in the southern region are at mid-to-high elevations, with low levels of conductivity and dissolved silicate (snow-melt dominated)

Streams in the northern region are at lower elevations, with higher levels of conductivity and silicate (groundwater mineral content)



Northern streams support higher levels of biological diversity than in the south

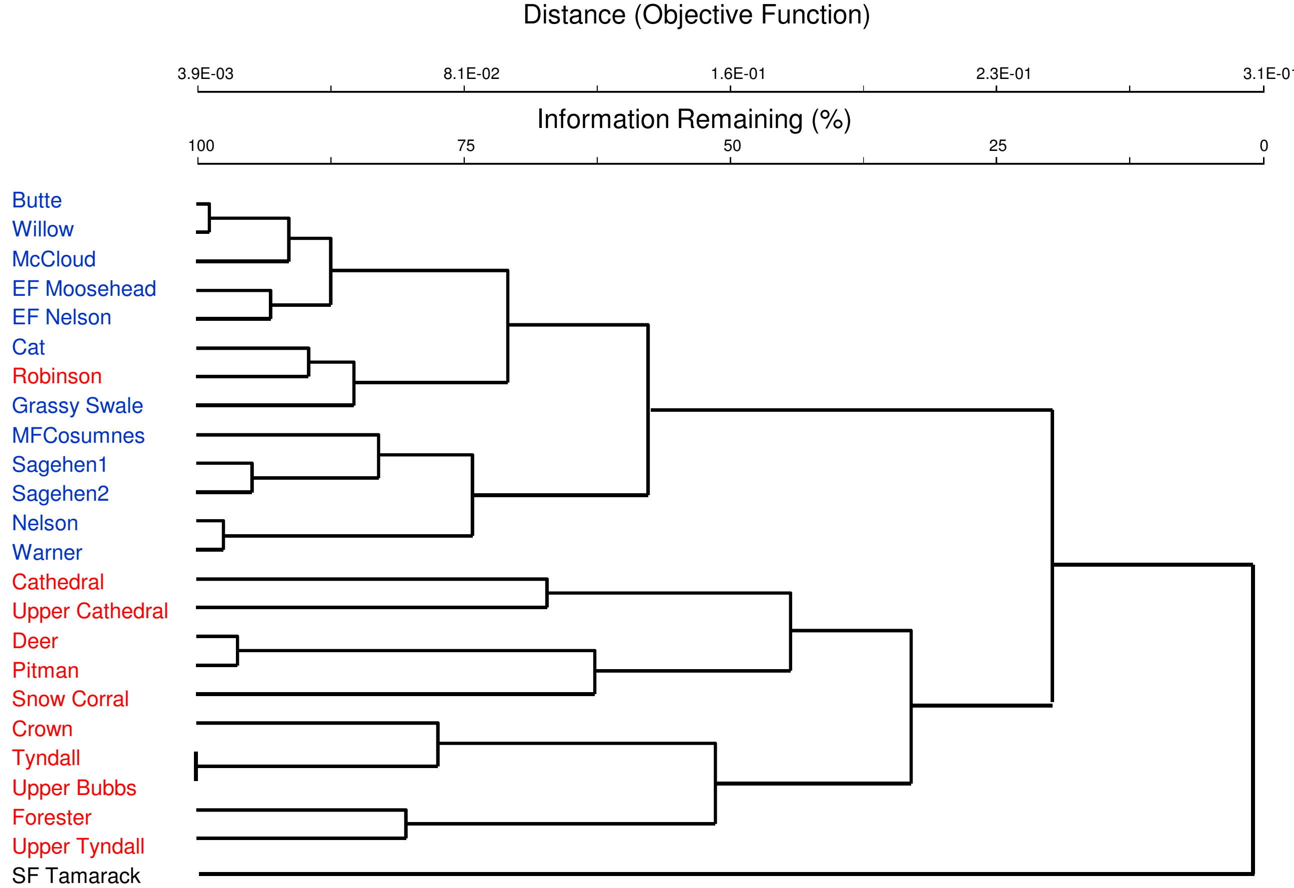




w/o M&Ms

Nearly 300 taxa identified to date Incl.M&Ms

Community Similarity Groupings

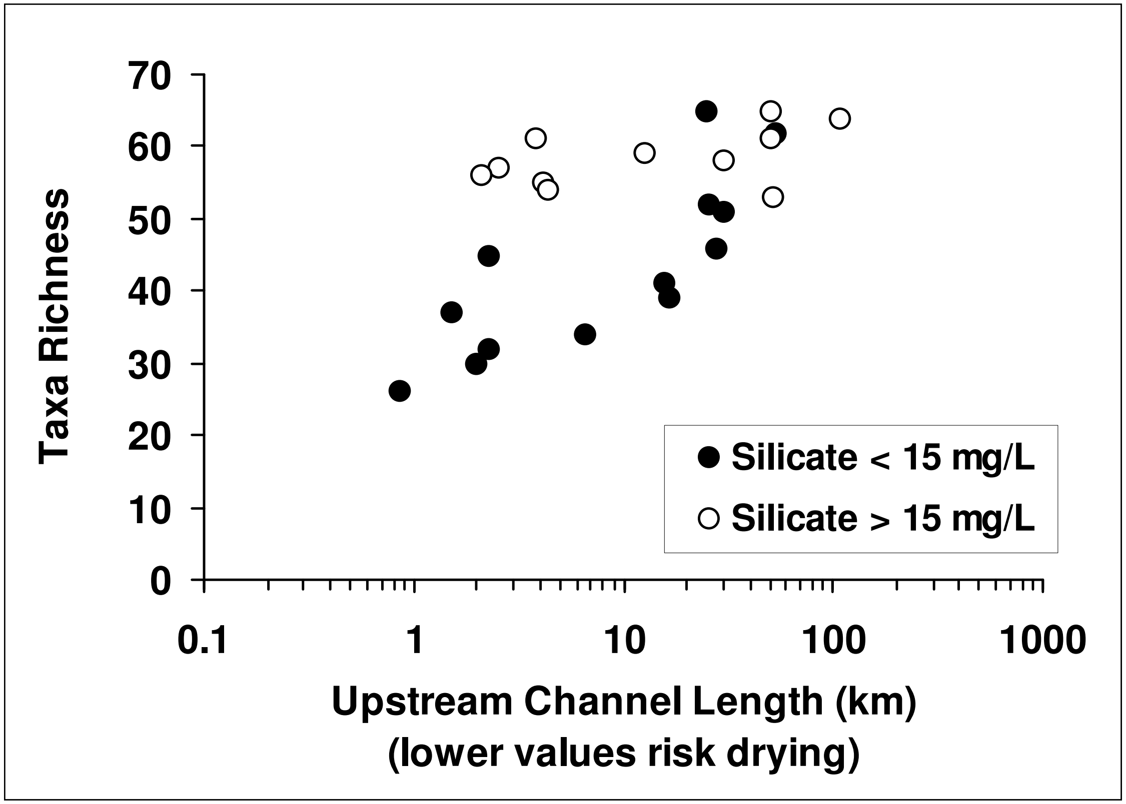


North of Yosemite

Yosemite and South

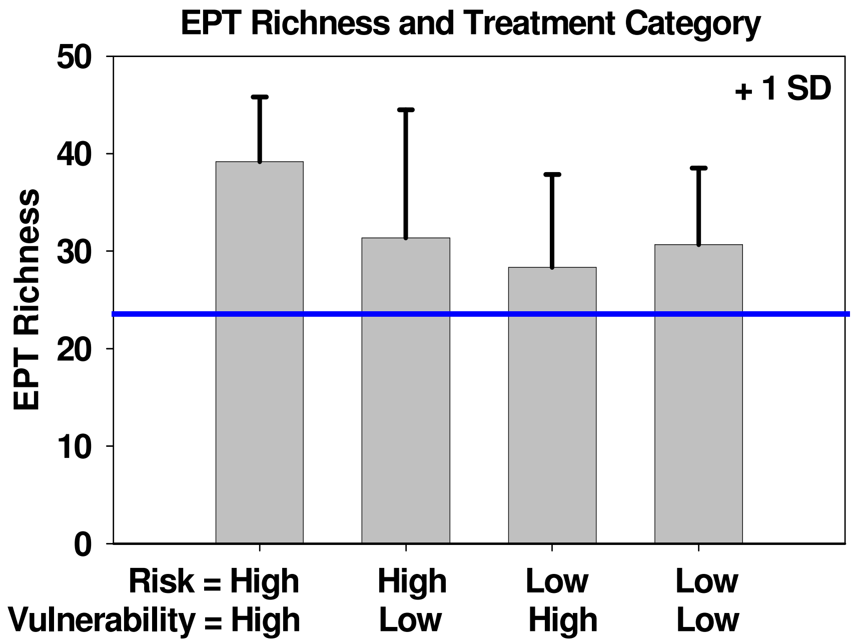
Intermittent channel = shortest upstream length, low SiO_2 snowmelt

Closer look at Intermittent flow: stress of periodic summer drying
>perennial upstream length used as indicator of dependable flow



Short headwater streams most susceptible, having least taxa richness.
But what protects some headwaters and not others?
>Groundwater inflows sustain baseflow (higher SiO_2) and resist drying
>low SiO_2 snowmelt risk drying but support more richness with increased channel length (=perennial flow)

Biodiversity present in treatment groups have similar initial richness levels for 2010, a near-average water year



Trait Character States:

- 79% of these taxa are cold-adapted*
- 89% are either semi- or uni-voltine (have ≥1 yr life cycles)
- 67% prefer riffle habitat (high flows)

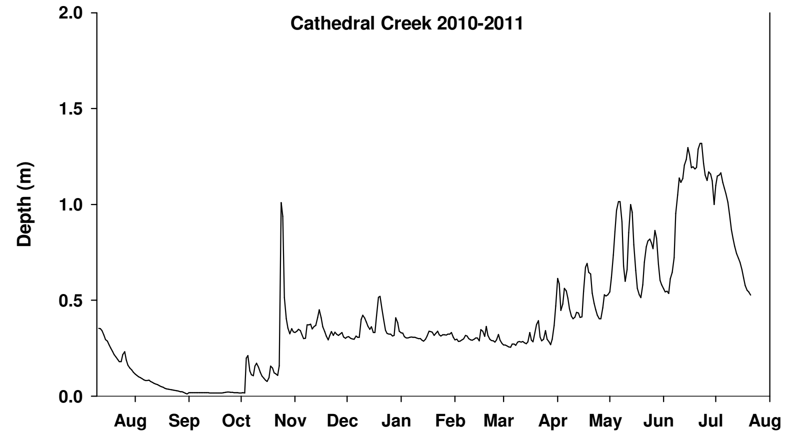
*except intermittent stream just 50%

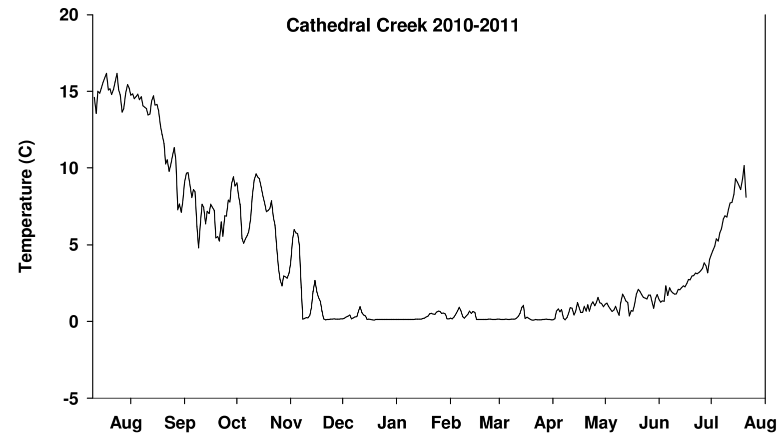
Statistical equivalence of treatment groups: Group with most risk and vulnerability also has the most scope for response.
All groups exceed the Sierra reference level for maximum EPT = 23 taxa [eastern Sierra IBI]

=Baseline for further comparisons

Flow Regime Types Observed*
(habitat ecological templates, after Poff and others)
Are there associated BMI community types?

- **1. Stable winter flows and temperatures during ice cover (though R on S may occur), rapid spring snow-melt and summer recession, prolonged cool temps (<10ºC)**
- **2. Winter rain and snow, instable ice-snow cover, rising flows through winter and spring, warm summer temperatures (≥15ºC)**
- **3. Stable groundwaters sustain high flows and cooler more constant temperatures (≤10ºC)**
- **4. Spatial intermittent flows, losing reaches, warm, variable**





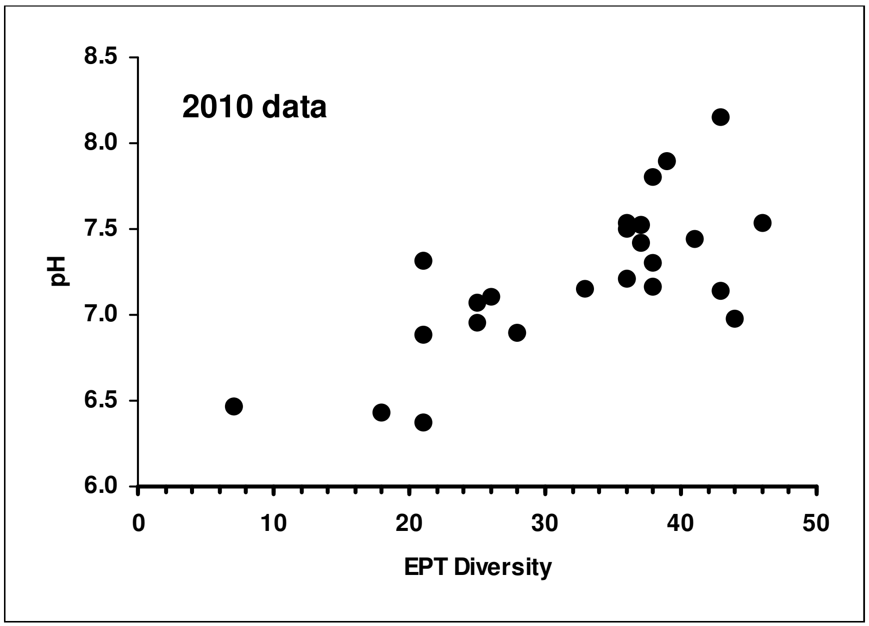
***1. Snow   2. Rain+Snow   3. Groundwater   4. Intermittent-Flashy**

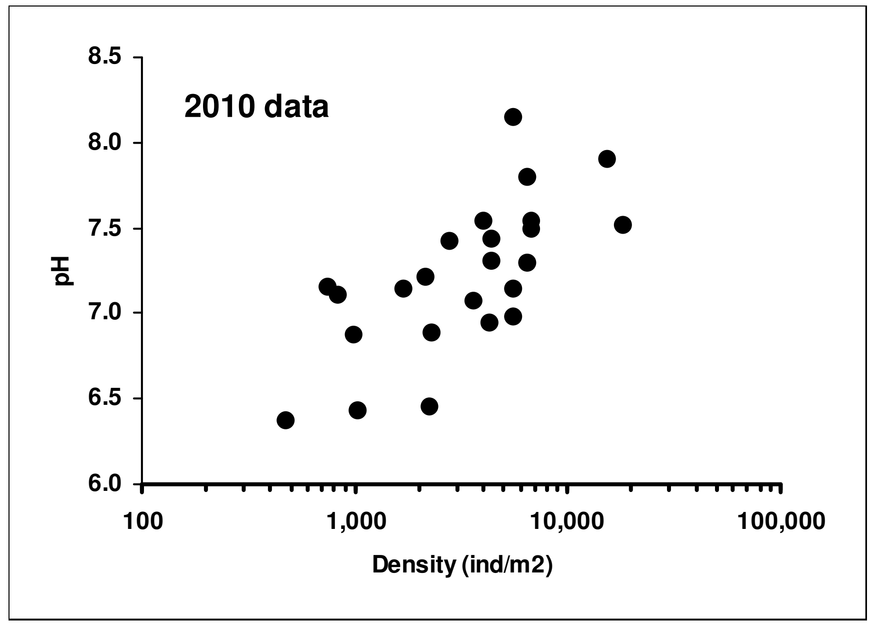
2011: high and prolonged spring runoff
water chemistry change: lower pH (-0.75 mean)

Wilcoxon signed-rank paired comparison 2010 to 2011
p<0.0001 (22 of 24 streams), <u>decreasing from an average of 7.22 to 6.47</u>

pH decrease with high runoff dilution of inflows,
most severe at streams with lower pH and less acid neutralizing capacity

Biological Consequences? ...depending on persistence of lower pH





2011 prelim data shows no loss of diversity/abundance: resilient so far

What's next: using the data obtained and maintaining the network into the future

- Sustain funding - possibly through interagency cost-sharing?
- Contribute results to California Climate Change Portal, and integrate into assessment reports of US-GCRP
- Apply flow and temperature recordings for the past year to validate and calibrate ungaged flow models, and use to back-cast past flow histories (use by USGS, DWR?)
- Further analysis of 2011 data to evaluate reference stability and biological indicator responses to record snowfall, high runoff, reduced pH, and delayed spring onset
- Do communities correspond to hydrographic regimes?

<u>Invite Collaboration</u>

- High elevation hydro- and thermo-graphs for model development >>rare data from headwater streams to share
- Stable isotope analysis of heavy water (^{18}O & ^{2}H) at each site to determine groundwater contribution (mixing models)

Conservation Applications

- Although there are many endemic and montane-adapted native species of aquatic inverts in the Sierra Nevada, biogeography and habitat requirements are poorly known, so surveys supply a basic biodiversity inventory
- Improved understanding of natural flow and temperature regimes, and microclimate of headwater streams
- Identify habitats & taxa changing most, and how these might be protected from climatic effects on hydrologic and thermal regimes > refugia & aquatic diversity management areas
- Extend GIS analysis of environmental resistance factors to assess habitat sensitivity to climate risk
- Use ecological trait analysis to assess biotic vulnerability
- Develop management framework to prioritize stream types for building resilience and protection of most vulnerable watersheds (riparian & meadow restoration, protect groundwater infiltration paths, reduce soil loss/debris flows by managing grazing, logging & road disturbance)
- USFS-NPS adaptive planning in climate change stewardship

conclusions

- Network is up and running and the biological indicators provide a strong foundation for detecting change (biodiversity & trait sensitivities to hydro-climate change)
- North – South stream groups show distinct differences in snowmelt vs groundwater influence on hydrology (and related water chemistry), and biological communities
- Biological richness of northern streams is ecological “insurance”, but this also means more to lose in a region with the most severe climate risk predicted
- Though having less biodiversity, southern streams harbor some vulnerable taxa with restricted distributions
- Intermittent drying poses a clear risk to sustaining biodiversity, esp. in snowmelt-dominated streams, but groundwater systems appear to be more buffered (confirming a predicted climate risk-resistance)
- Lower pH an unexpected change with uncertain effects under extreme flow conditions, but so far communities of BMIs appear stable under this stress


Questions?