Anticipating and Accounting for the Influence of Climate Change on Stream Hydrology and Biology in the Sierra Nevada

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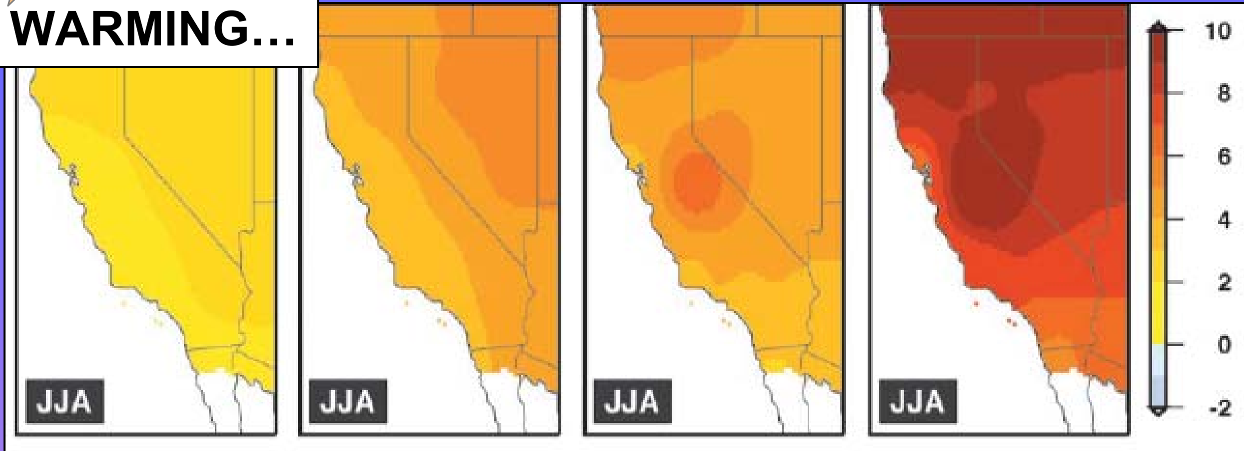
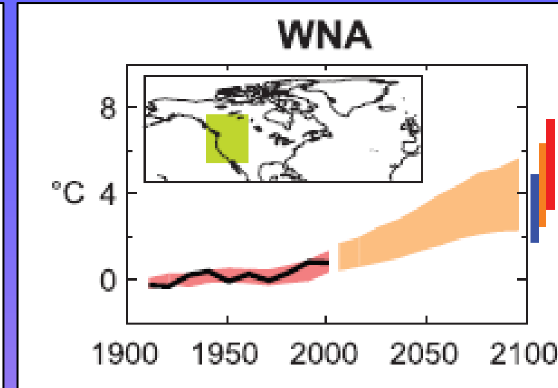
WARMING…





IPCC-Fourth Assessment

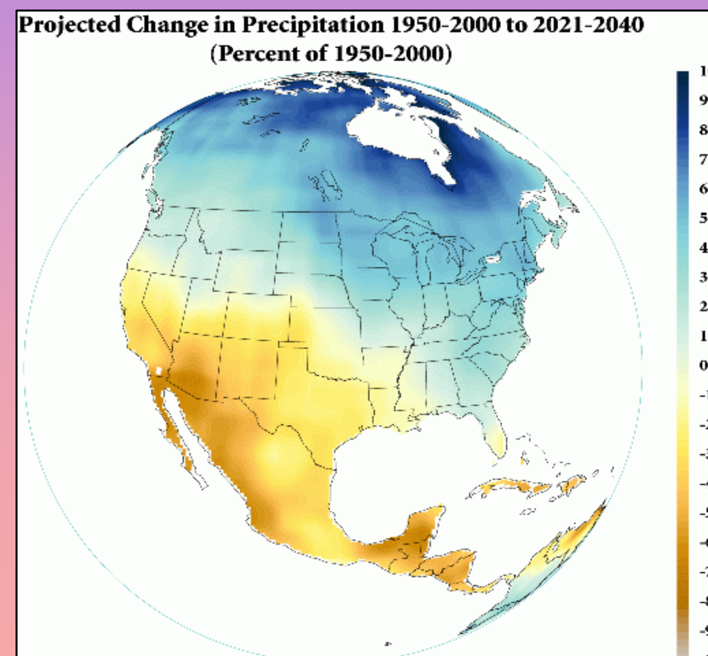
Climate models using different CO_2 emissions scenarios for California: forecast summer warming of 1.2 - 3.1°C over next 25-50 yrs, and from 2.1 - 8.3°C by end of century, and will continue….

Alternative models June-July-August

From Our Changing Climate: Assessing the Risks to California, 2006

Most pronounced in interior & Sierra….

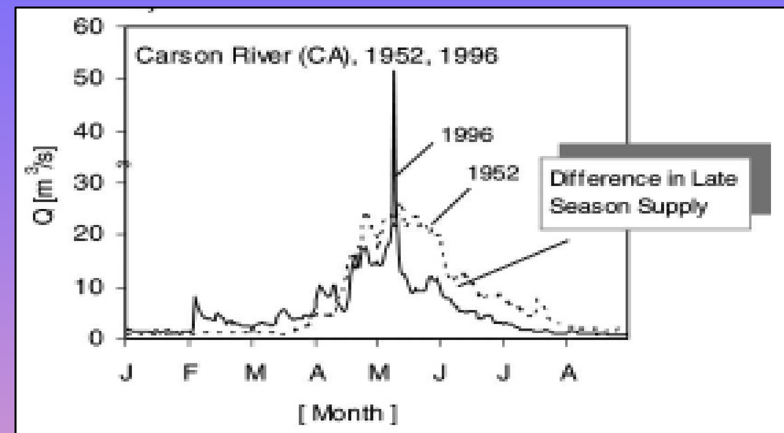
Transition to perpetual drought in southwest N. America – a 10-20% decline in precipitation by end of century (wetter in north).



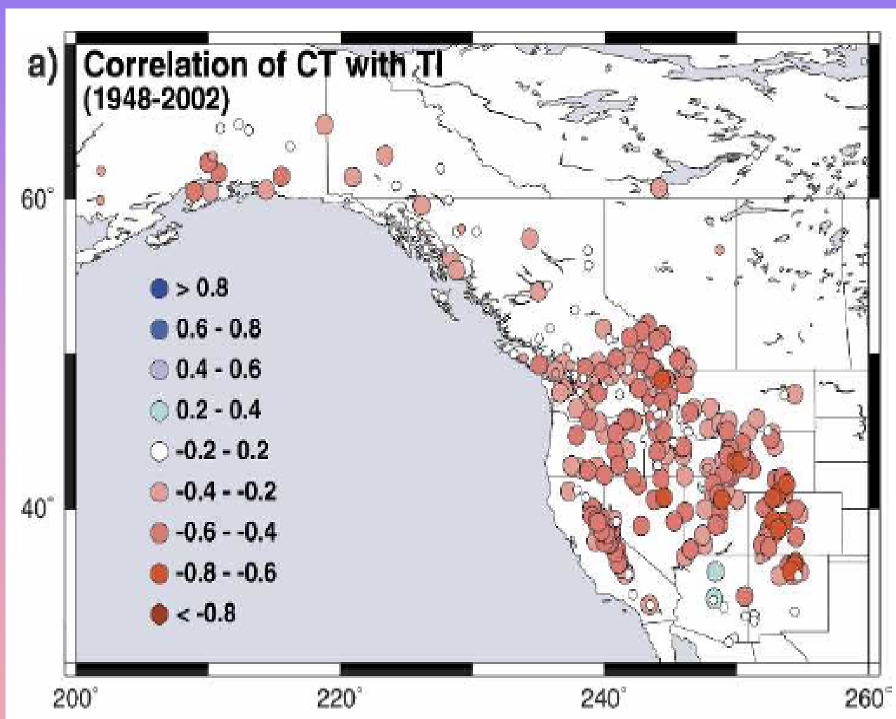
From R. Seager 2007, Lamont-Doherty Earth Observatory

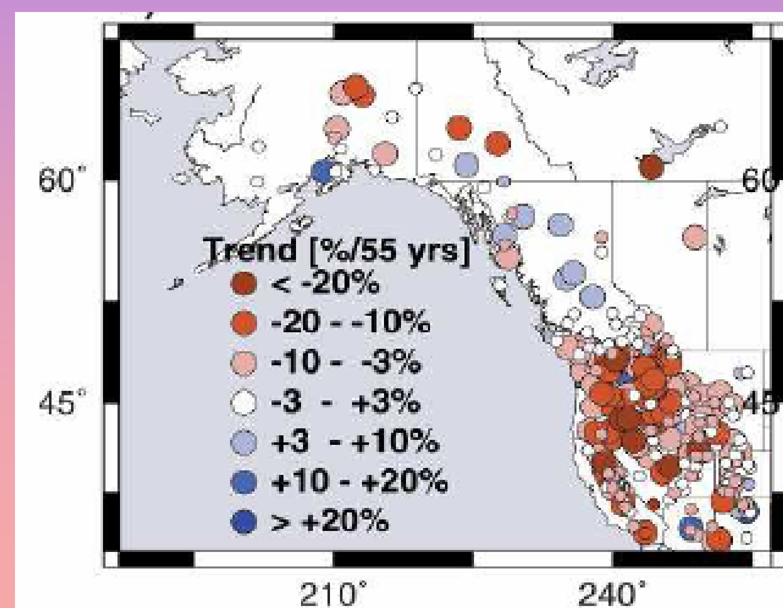
Evidence for regional changes that have already occurred:

Earlier run-off & decreased fraction as snowmelt (more rain than snow)



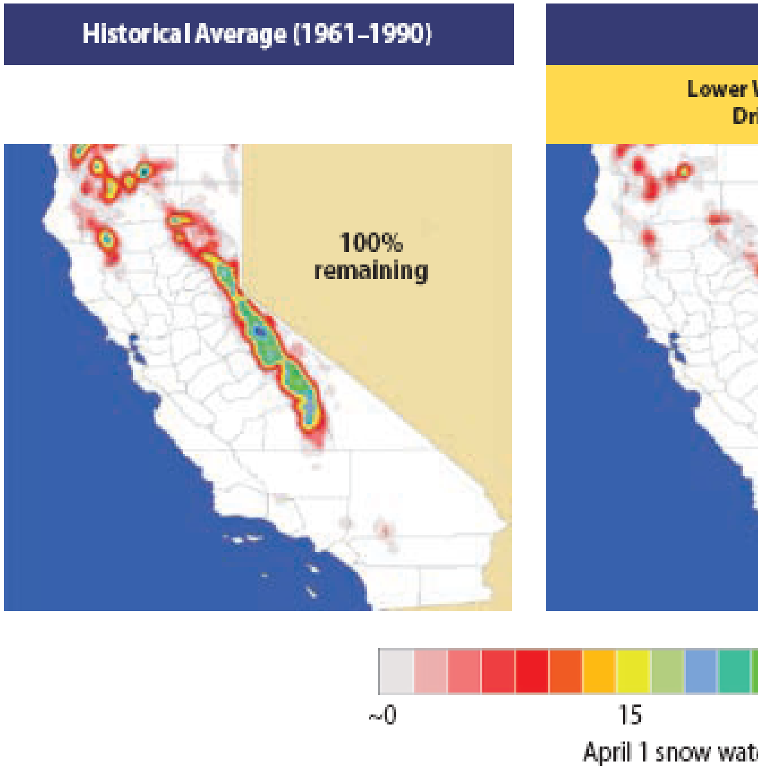
Warming trends in climate correlate with earlier flows



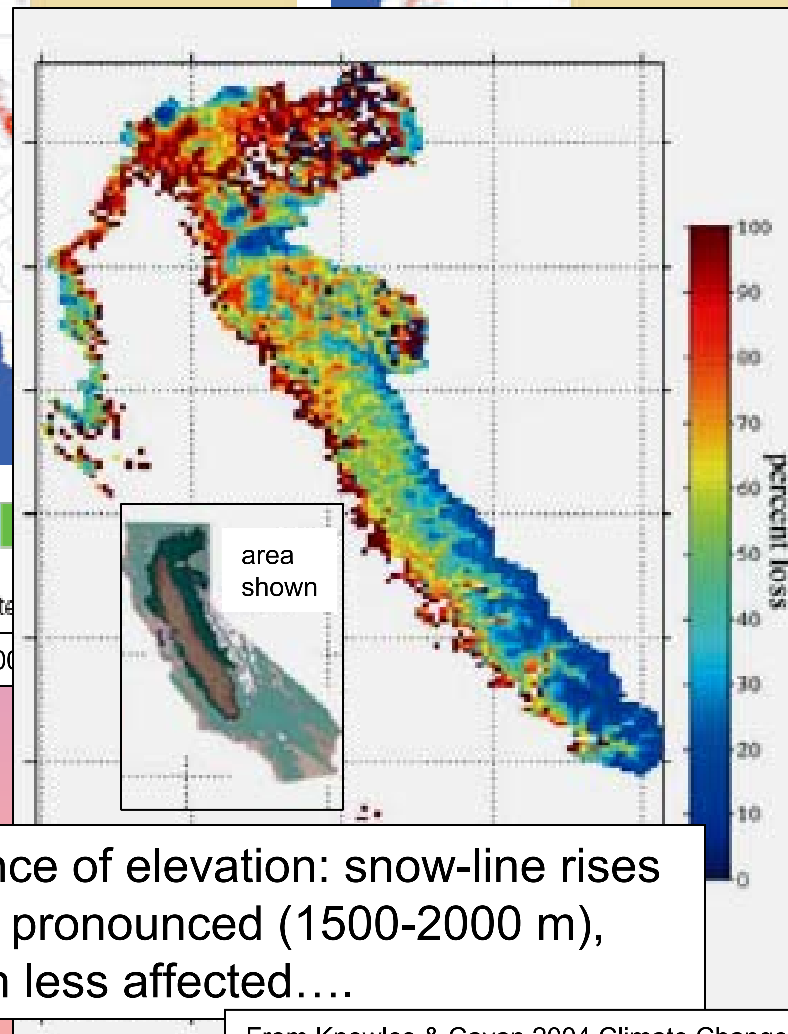


From Stewart, Cayan, Dettinger J.Climate 2004

Projected loss of snowpack:



From Our Changing Climate: Assessing the Risks to California, 200



Percent loss by 2060, showing importance of elevation: snow-line rises & mid-elevation snow volume loss most pronounced (1500-2000 m), with east-slope and high elevation south less affected….

From Knowles & Cayan 2004 Climate Change

Increased flood frequency and intensity, with greater potential for erosion and sediment loading

With increased proportion of winter precipitation falling as rain rather than snow, there is greater probability of rain-on-snow events, unleashing record floods and erosive forces (>>sediment transport & deposition)

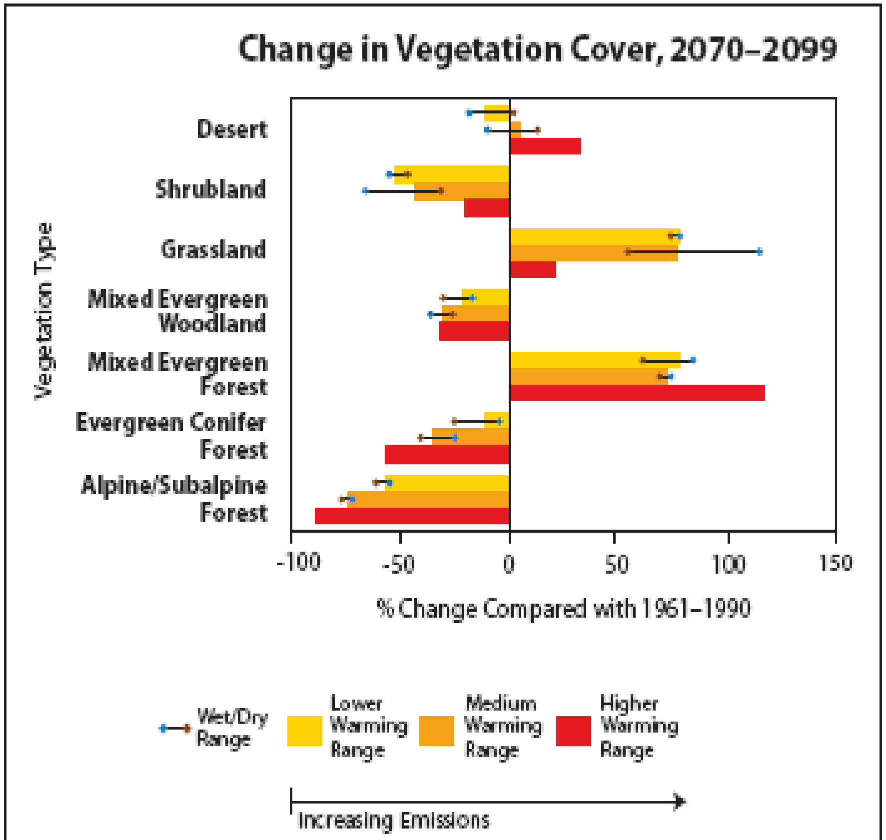
Models also predict greater hydrologic variability – extreme conditions of high and low flows becoming more frequent

With warmer conditions, fewer streams will have permanent ice cover and an insulating snow layer

> in low sub-freezing winter conditions, radiative heat loss from <u>open streams</u> causes formation of frazil-anchor ice, creating ice-dams, dewatering, and abrasive channel flood-scouring on break-up

Loss of alpine and evergreen conifer forests:

- Alpine, subalpine and coniferous forest communities are forced "off the mountain" (~50%+ loss of Pine forests, alpine meadows)
- Grasslands and mixed evergreen forest come to dominate (Doug. Fir, Madrone, Oaks)
- Accompanied by increased and more intense fire frequency



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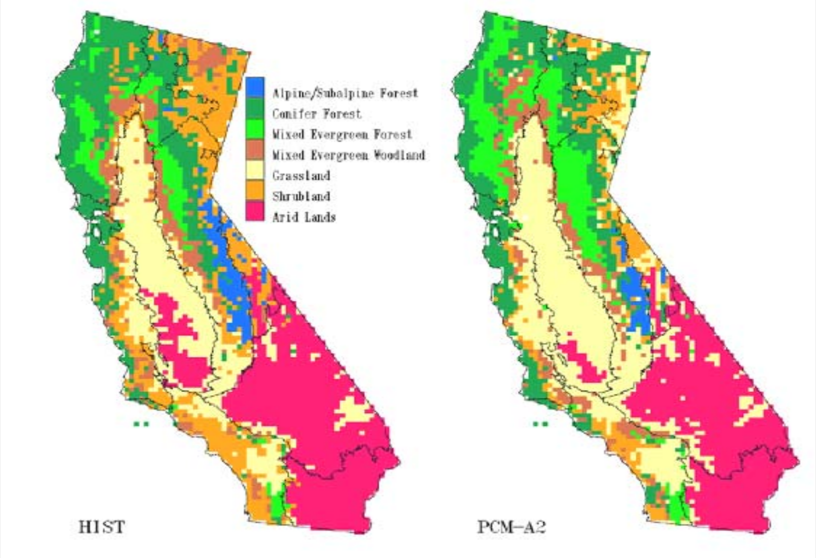


< model forecast example

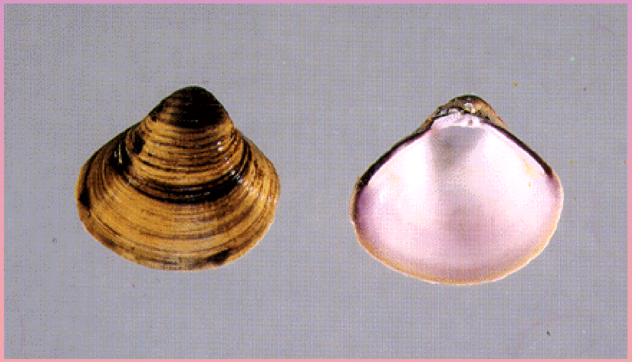
From Lenihan et al. 2006,
California Climate Change Center

Heat, Drought, Floods, Fires and Pestilence?

Disturbed habitats conducive to invasion of exotics – warmer, hydrologically variable, higher conductivity, erosion, sedimentation – all conditions promoting expansion of exotics and new warmwater neotropical fauna? >>pestilence = ecological "disease"

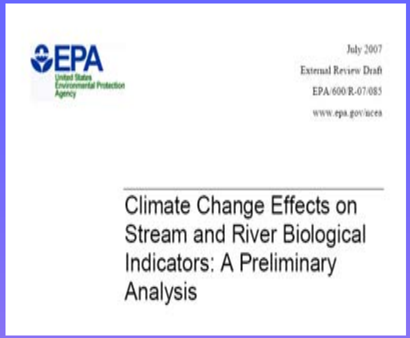
Potamopyrgus antipodarum
New Zealand Mud Snail

Dreissena bugensis
Quagga mussel



Corbicula fluminea
Lesser asiatic clam

EPA report on climate change effects on stream and river biological indicators – summary:


EPA
United States Environmental Protection Agency

July 2007
External Review Draft
EPA/600/R-07/085
www.epa.gov/ncea

Climate Change Effects on Stream and River Biological Indicators: A Preliminary Analysis

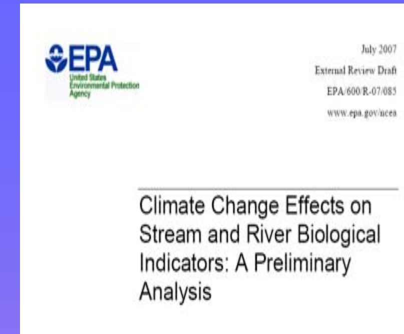
<u>**Expected responses of aquatic invertebrates**</u>:
(1) changes in **range and distribution** of species
(2) changes in **phenology**
(3) evolutionary **adaptations** in morphology, physiology, behavior

>Migration to higher latitudes / elevations? Earlier emergence?

Small, short-lived, abundant organisms may have greater capacity for adaptation but only limited adaptation is likely as phenotypic responses are not expected to keep pace with the rate of warming.

<u>**Case Study: How long would it take to detect an effect on metrics**</u>**?**
Using mid-Atlantic data set of specified variability in reference condition, and based on studies of thermal discharge effects, it would take <u>15 years</u> to detect with 95% confidence, the loss of taxa richness expected with highest warming rate projected: 6.5 °C by 2100 and 4.5 taxa lost per °C.
Warming of 1°C could be detected on average, across reference sites.
At the lowest warming & loss rates, it would take 100+ yrs to detect.

EPA Report, continued: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Climate Change Effects on Stream and River Biological Indicators: A Preliminary Analysis

<u>Another Case Study: How is assessment of reference from test influenced by climate change (hydrologic variability and warming)?</u>

Wet and dry hydrological extremes and warmer temperatures simulated by partitioning such conditions from existing data sets: Under these conditions (wetter, drier) and increased temperature, the reference condition showed loss of taxa diversity and IBI scores, and more so than at already degraded sites. This suggests that reliability of the reference standard in detecting impairment deteriorates with climate change (especially true of the drought scenario).

Decreased signal:noise ratio accounted for the loss in discrimination of reference from test.

Concludes that using fixed reference sites in a targeted monitoring plan (or repeats at a subset of all references sampled) would be the most powerful statistical design for detecting climate warming effects.

Probabilistic sampling of references adds random variability to each successive data set and so could obscure climate change effects.

Implications for Sierra Nevada Stream Invertebrates

- ***Low summer flows will result in conversion of many perennial streams to intermittent habitats (esp. in glaciated terrain), eliminating vulnerable taxa (e.g. cold stenotherms, long-lived, and obligate aquatics)***
- ***Varied spatial distribution of predicted effects suggests that gradients of ecological impact will exist north-south, east-west, and with elevation: testable hypotheses and anticipated vulnerabilities***
- ***East-West oriented drainage systems will have no high-latitude escape, just as low elevation watersheds will have only limited escape from warming***
- ***High-elevation montane taxa may be at ecological "dead-ends" - barrier of escape to higher elevation refugia formed by Sierra crest: the more protected east-slope drainages may be inaccessible to west-slope fauna***
- ***Mid-elevation streams in conifer forests on the western slope have been found through comparative surveys to have the highest levels of macroinvertebrate diversity in the Sierra Nevada (and many endemics) but this is where most forest cover change and snowpack will be lost***

Accounting for changes….

- Develop specific indicators of change related to temperature tolerance ("losers and winners")
- Set reference standards NOW, and with existing data – and track over time at fixed "nature preserve" stations
- Establish a geographic monitoring network to test predictions of models
- More extensive monitoring of flow and temperature regime in mid-to-high elevation streams (especially extremes of summer temps and low flows)

Potential indicators of thermal sensitivity / tolerance from Sierra Nevada stream surveys (SNARL data set)

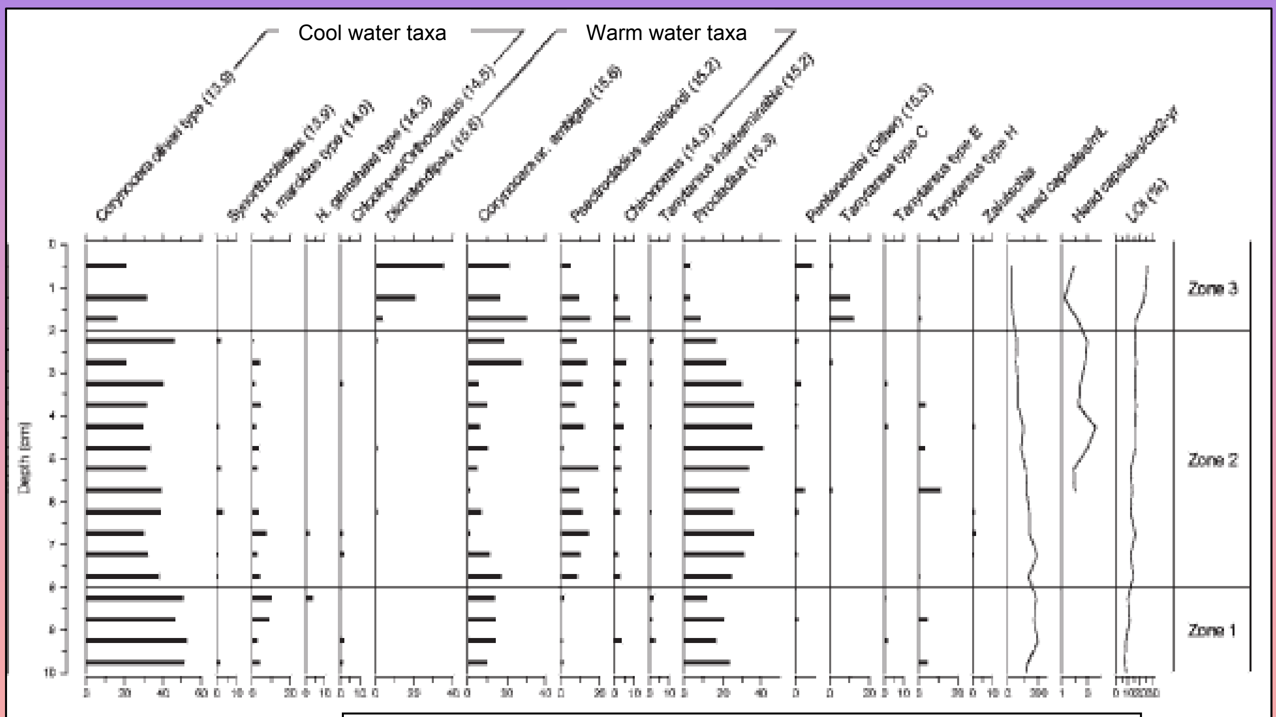
Thermal-Sensitive Taxa	Occurences (of 134)	Temperature Weighted-Avg
Arctopsyche.grandis	32	10.6
Atherix.pachypus	20	10.6
Drunella.doddsi	58	11.3
Rhithrogena	66	11.6
Attenella.delantala	45	11.6
Rhyacophila.sibirica	41	11.8
Cinygmula	86	11.9
Pericoma	48	12.0
Rhyacophila.arnaudi	32	12.1
Sweltsa	80	12.2
Drunella.spinifera	34	12.4
Stempellinella	37	12.5
Doroneuria.baumanni	48	12.6
Eukiefferiella.devonica	30	12.7
Testudacarus	49	12.8
Rhyacophila.acropedes	49	12.8
Yoraperla	29	12.8
Micropsectra	96	12.9
Caudatella.hystrix	34	12.9
Serratella	96	13.0

- Weighted-average abundance under varied field temperature conditions (following Yuan)
- Sensitive w/ WA ≤13 °C
- Tolerant w/ WA ≥17 °C

Thermal-Tolerant Taxa	Occurences (of 134)	Temperature Weighted-Avg
Simulium	109	17.0
Phaenopsectra	22	17.3
Hygrobates	19	17.3
Hydropsyche	18	17.3
Synorthocladius	27	18.2
Wormaldia	21	18.8
Apedilum	18	19.2
Pentaneura	34	19.4
Pseudochironomus	20	20.5

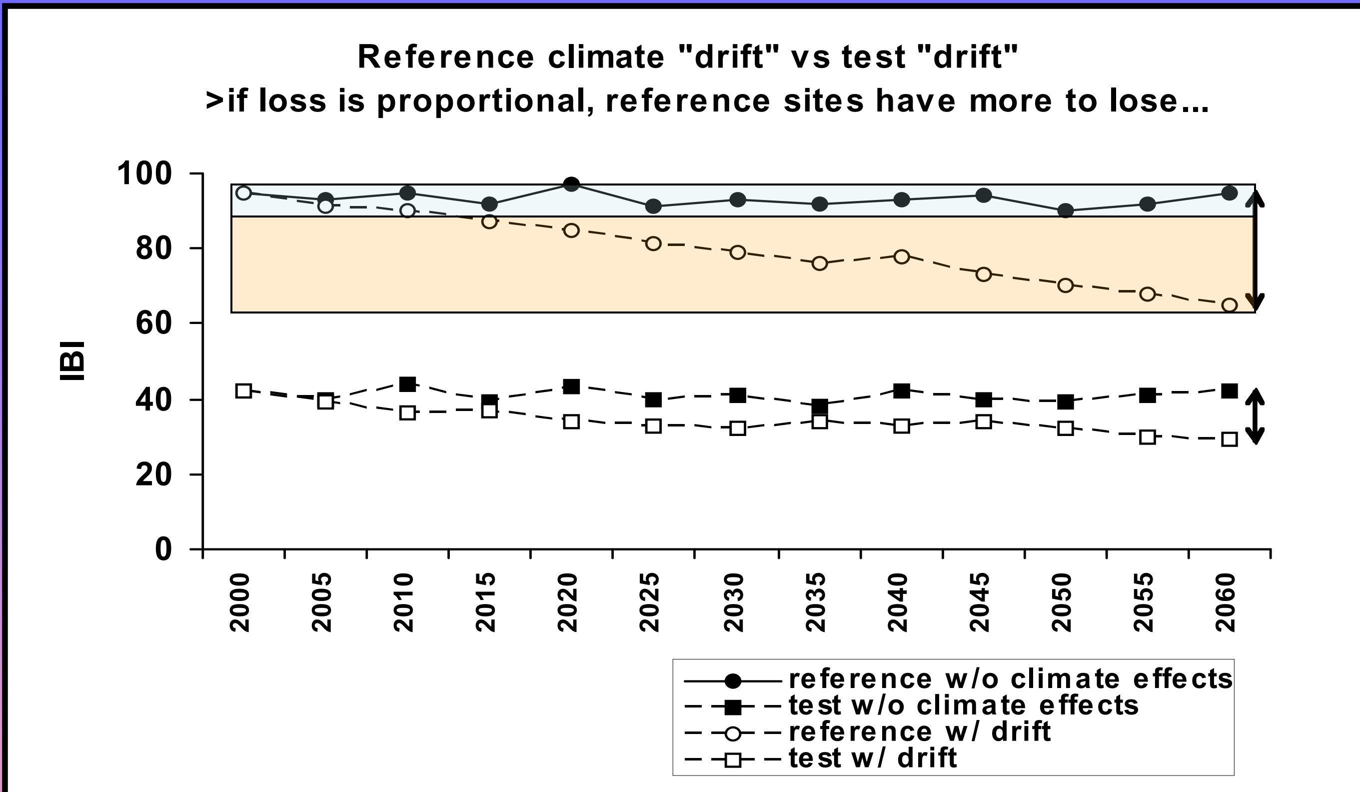
Climate reconstruction and inference of ecological change using chironomid thermal proxies in lakes

- David Porinchu (Ohio State) and colleagues:
  Using a calibration data set based on distribution of living midges with water temperatures from >50 lakes, examination of sub-fossil head capsules in short-cores from selected lakes showed changes in midge community over the past 30 years that indicate an increase of 0.5 to 1.0 °C has occurred (matching regional trend in climate warming)



From Porinchu et al. 2007 Arctic, Antarctic and Alpine Research

Accounting for Climate "Drift": Set References NOW & track…



Less signal: mean R/T ↓

More noise: R variable

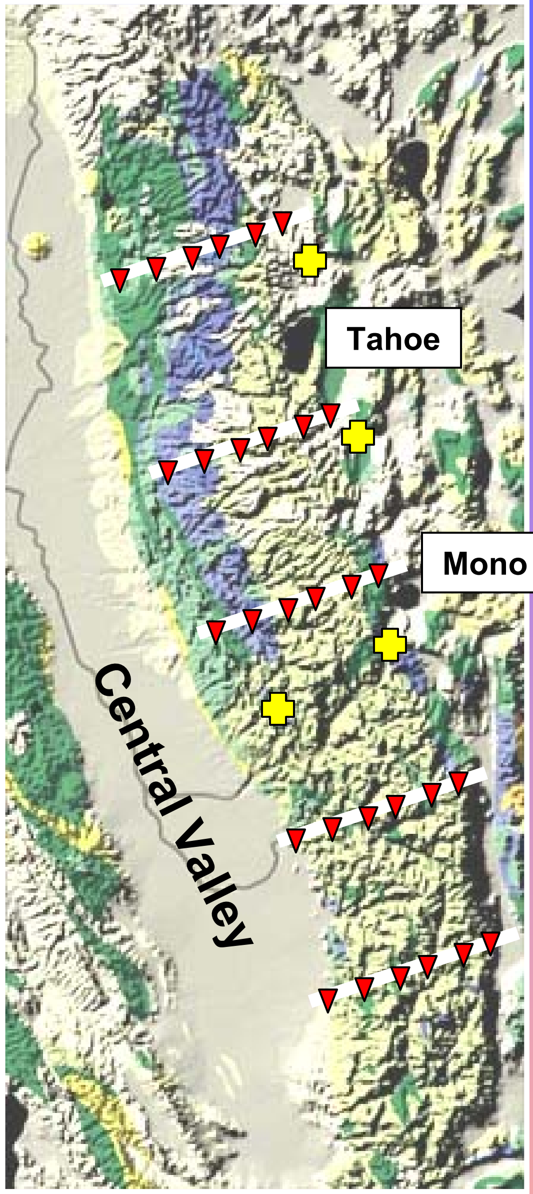
>> Loss of discrimination

Sampling design and monitoring network

- targeted design, repeated monitoring of protected references (isolate effects of climate change at fixed sites)
- monitoring of test sites with and without impairment sources removed (gauge climate relative to local degradation)

Geographic Array
Optimal design for detecting climate change effects

- **Sierra Nevada monitoring network arrayed by latitude, elevation, and east-west orientation (5 x 6) – used to test predictions of down-scaled climate models (repeat 5-yr intervals)**
- **Legacy sites (5-10 yrs data) at mid-elevations: Kings R. EW, Convict Creek, Sagehen Creek, Mountaineer Creek….others?**
- **Probabilistic re-sample from population of sites surveyed under different programs**



but <u>no GCC stream assessment plan</u> currently in place for USFS or NPS federal lands in Sierra…..
NPS vital signs plan has given “high priority, but no funding”

FORECASTING LOSS OF BIODIVERSITY……
Species-area models often used for predicting ultimate effects of climate change on loss of species diversity (assumes entire areas become uninhabitable…)

But loss of species overestimated because models are inadequate to simulate migration and adaptation responses that avoid extinction

While this approach is flawed (Botkin et al. 2007 BioScience) it could be improved by instead modeling changing heterogeneity of habitat patches (e.g. Thermal refugia in groundwater inflows? Segments of perennial streams becoming intermittent? Geographic gradients?)

MEASURING BIOLOGICAL INTEGRITY….
Extinctions are forever, but –

If we required extinction as the sole measure of impairment in bioassessments, how often would we detect impact?

Measures of changes in ranges of distribution, population density, ecological function, community structure, phenotypic heterogeneity, native and endemic diversity within and between communities, these are more proximate and relevant impacts to be looking for…