

# Climate Change Effects on Rivers and Streams

David Allan

University of Michigan

dallan@umich.edu

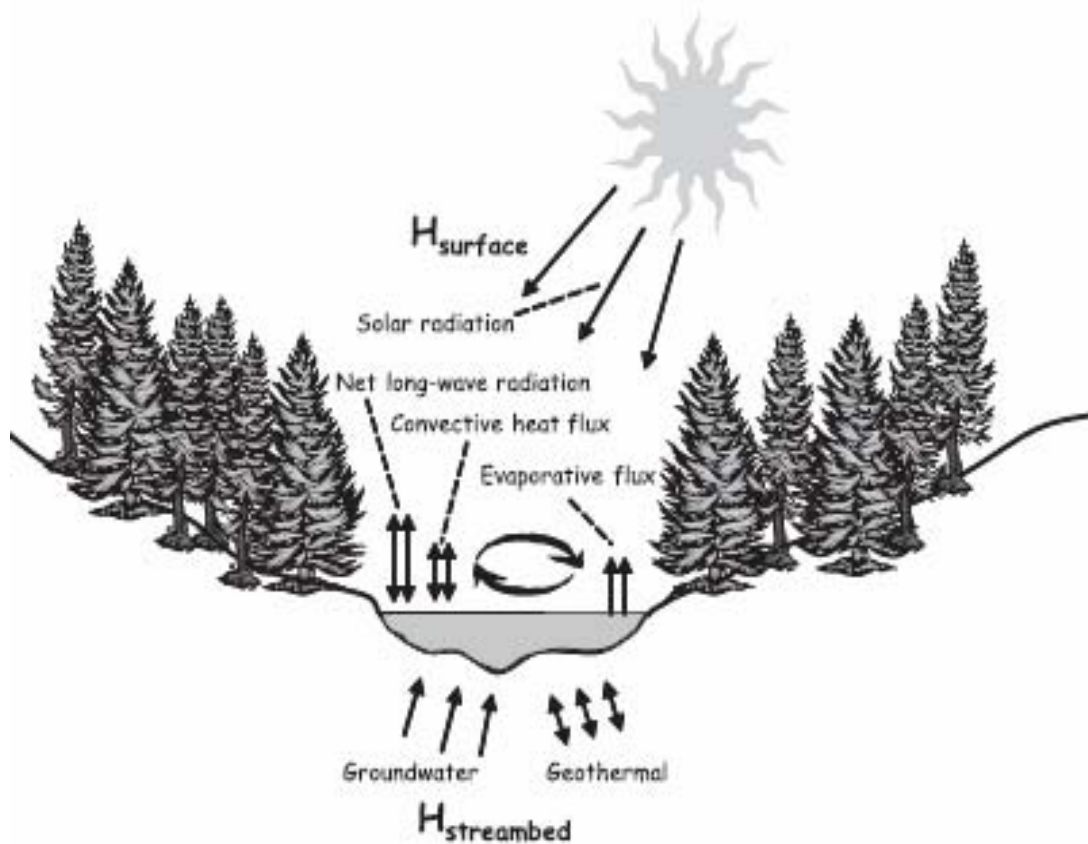
# Primary Questions

- How is climate change likely to affect river and stream ecosystems?
  - Mechanisms
  - Evidence
- What are the implications for management?
  - Assessment tools
  - Management opportunities

# Mechanisms / Affected Processes

- Temperature
  - Daily, seasonal, and interannual variation
  - Stream size (volume) / longitudinal position
  - Latitudinal position / Elevation and topography
- Flows
  - Daily, seasonal, and interannual variation
  - Stream size / longitudinal position
  - Geography and climate
- Indirect effects
  - Basal resources
  - Disturbance regime
- Interactive effects
  - Multiple stressors influence stream ecosystems

# River heat exchange processes



Heat exchange processes:

Solar (short-wave) radiation

Long-wave radiation

Evaporative heat flux

Convective heat flux

(Listed in declining order of importance)

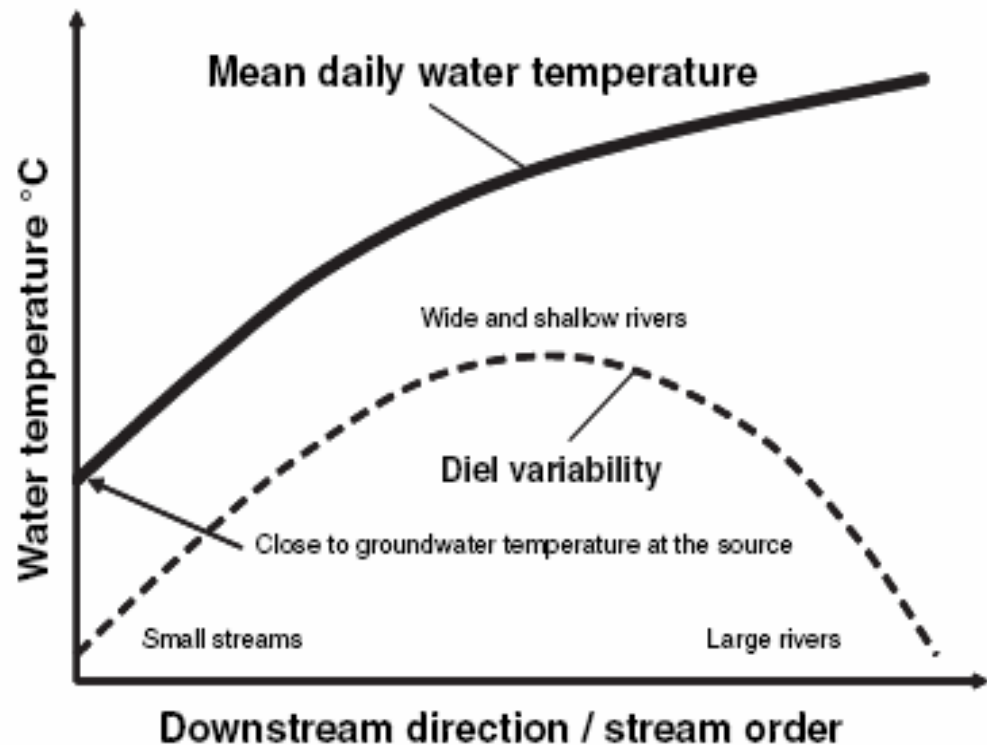
Caissie (2006)

# Size and longitudinal position

Stream temperatures are close to groundwater temperatures near source

Streams warm in the downstream direction

Diel variability increases initially, then declines due to thermal inertia of larger water volume

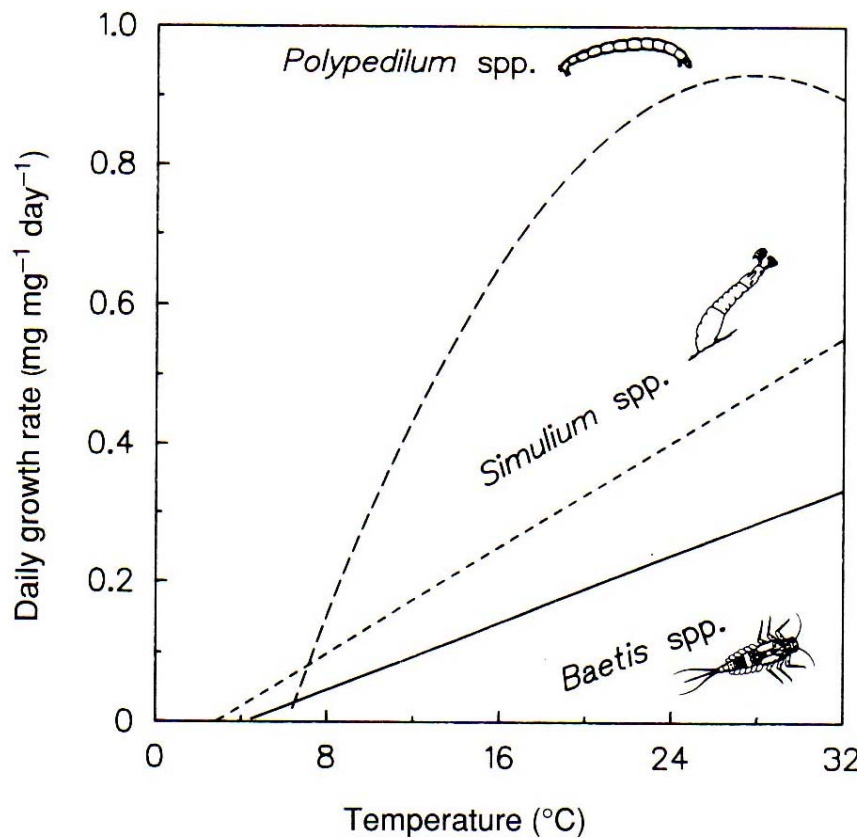


Caissie (2006)

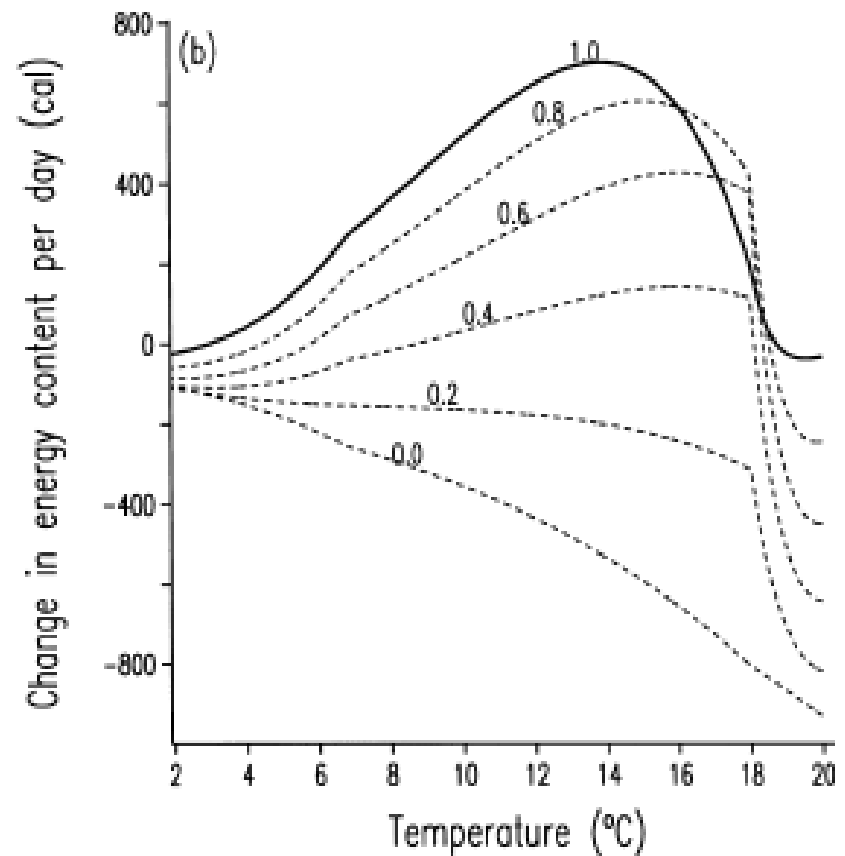
# Influence of warmer water temperatures

- Dissolved oxygen and water quality
- Biological productivity
- Bioclimatic envelopes
- Phenology, life cycle events
- Species interactions

# Increased biological production



Benke 1993



Elliott and Hurley 2000

# Thermal Niche

## Thermal niche (lab preferences)

	cold	cool	warm
4 °C niche	11-15 °C	21-25 °C	27-31 °C
10 °C niche	8-18 °C	18-28 °C	24-34 °C

Magnuson et al 1979

## Distributional studies using mean July temperatures

cold	cool	warm
< 19 °C	19 - 22 °C	22 °C

Wehrly et al 2003

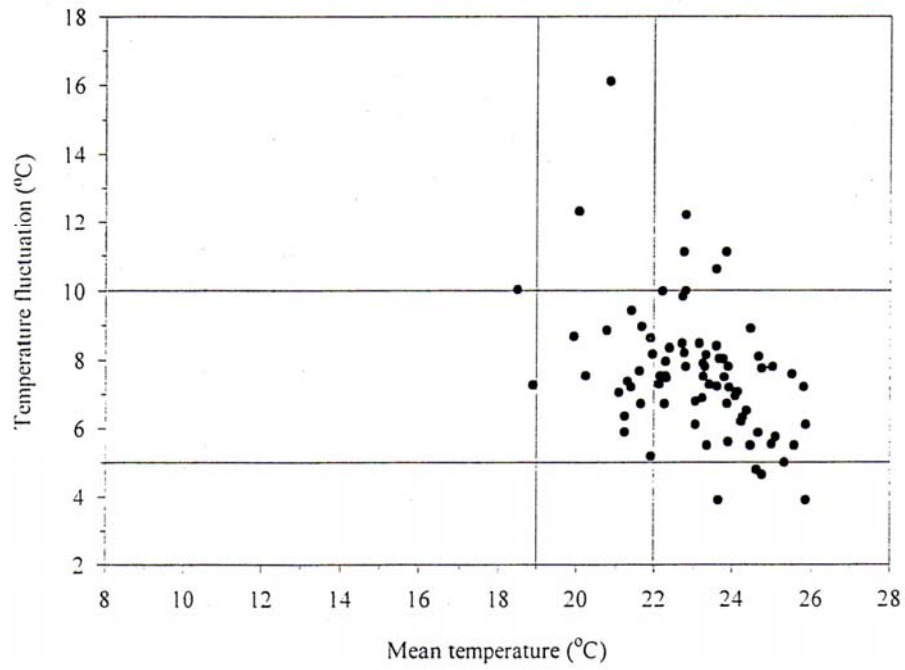
Maximum tolerances better studied than minimum

Diversity of warmwater fishes > coldwater fishes

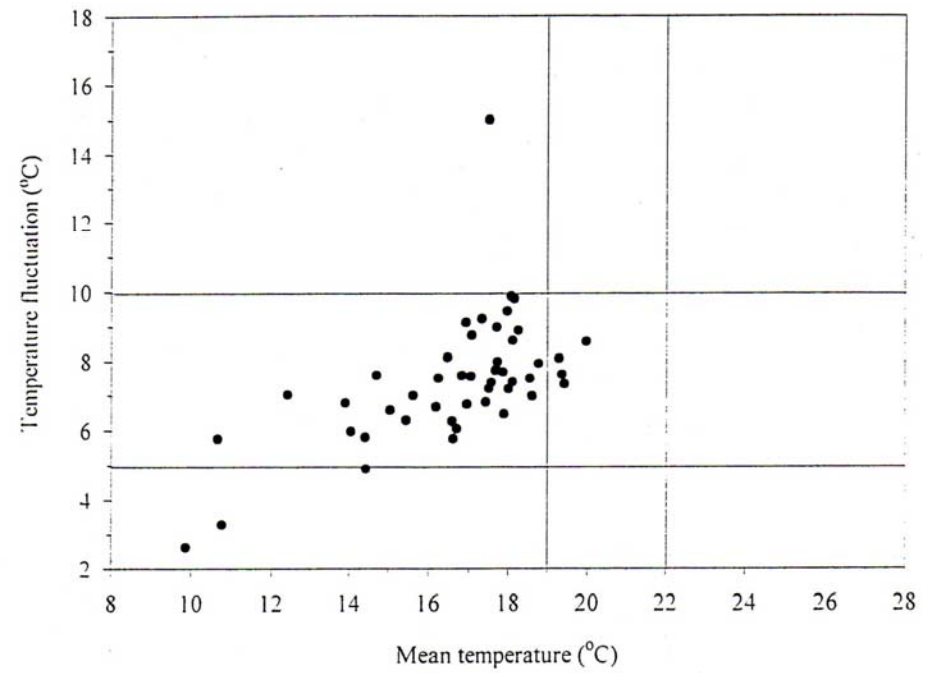
*Warming will often increase diversity*



## Smallmouth bass



## Brook trout



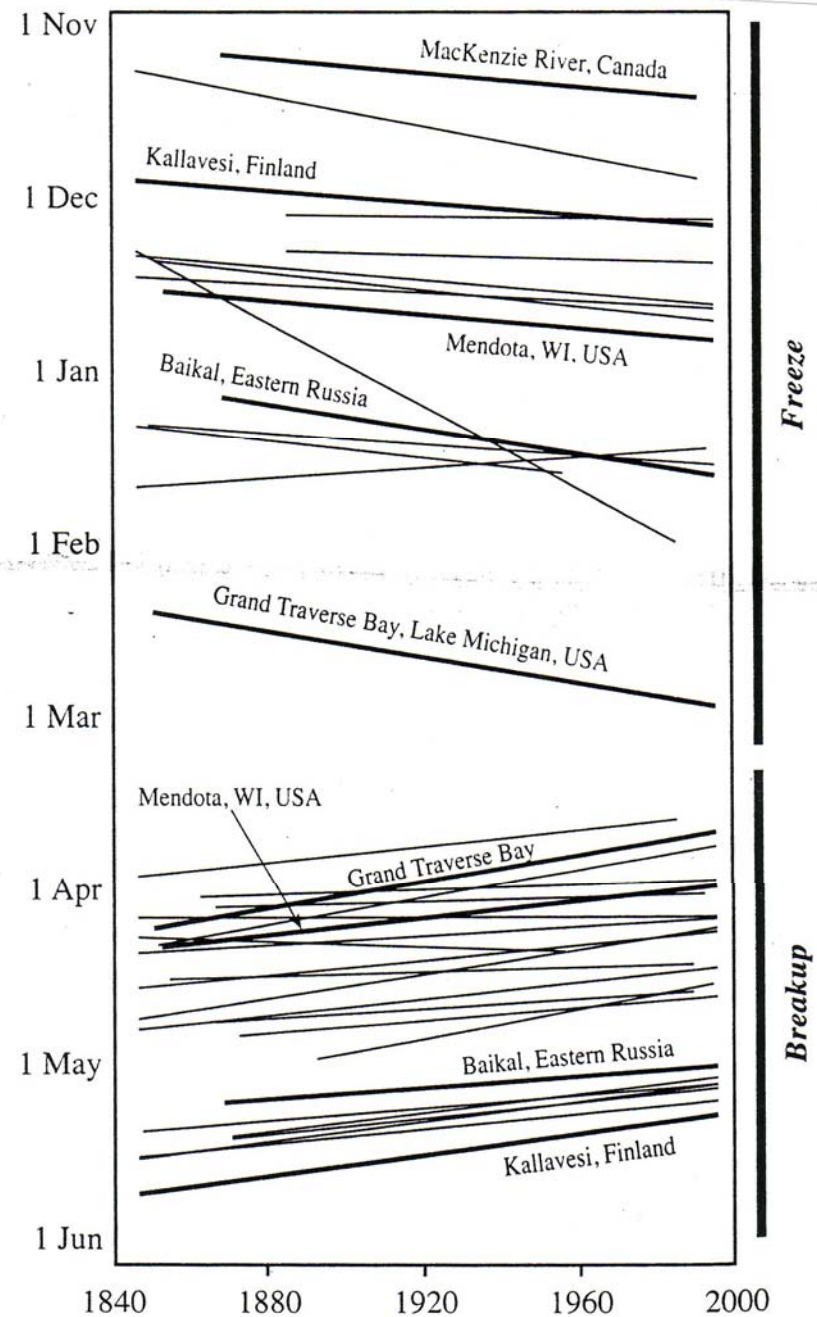
Wehrly et al 2003

# Evidence of stream warming

Strong evidence of changes in length of season

Freeze dates are later, thaw dates are earlier

From Magnuson J and IPCC reports

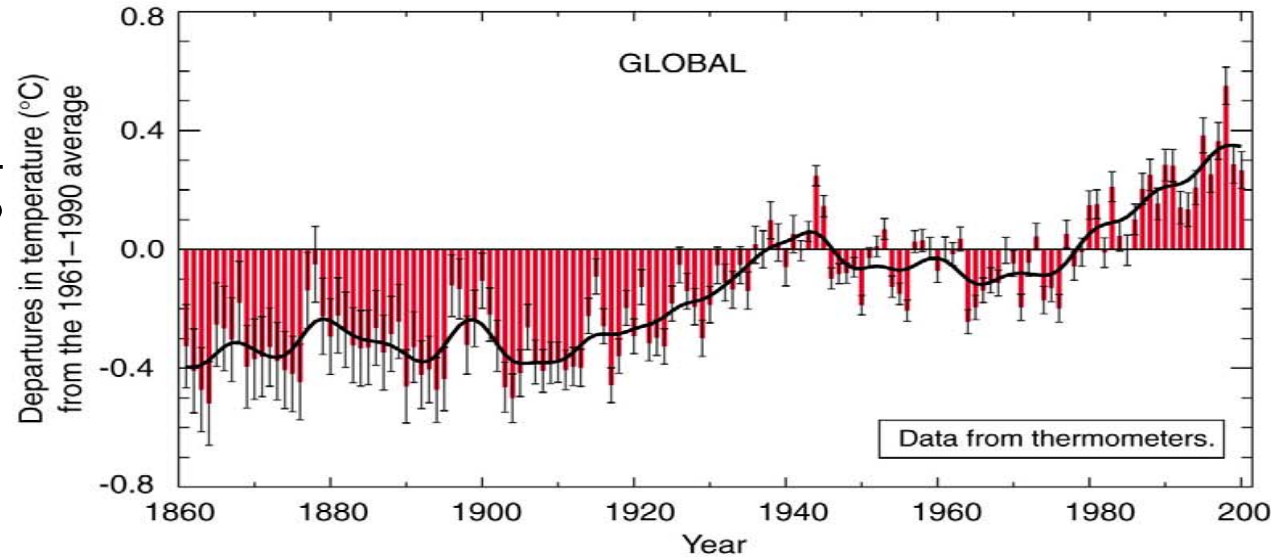


# Evidence of stream warming

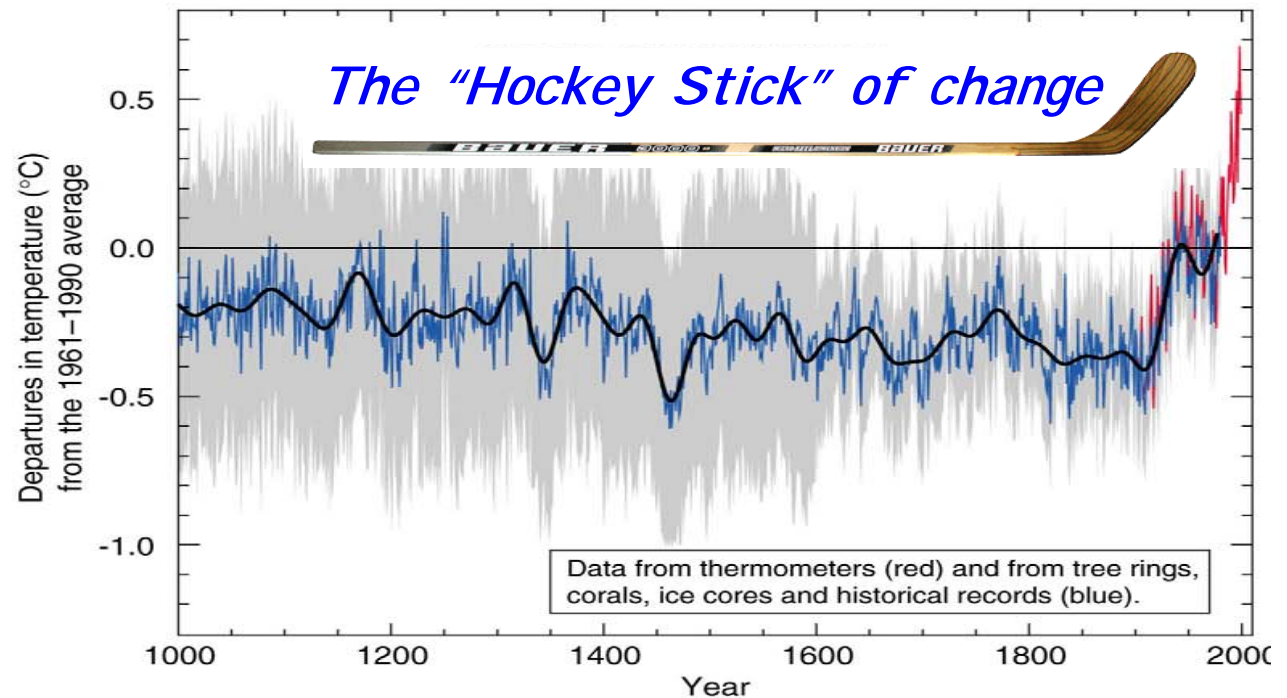
- Relatively few long-term data records
- No “hockey stick”
- Many confounding influences
  - impoundments
  - heated effluents

Need for additional study

(a) the past 140 years



(b) the past 1000 years



Interannual variability in water temperature over 20<sup>th</sup> Century at three sites in Austria.

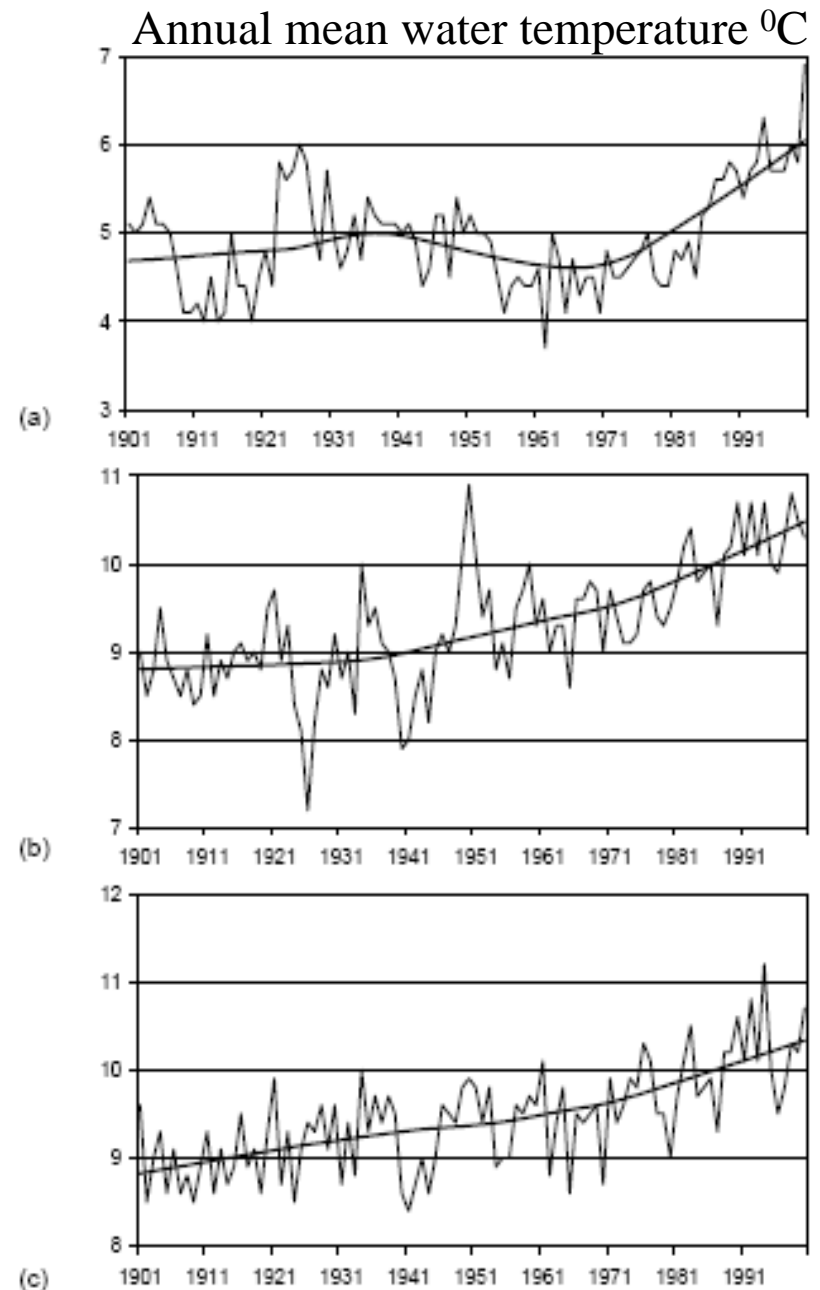
(a) Mittersill, a mountain catchment;  
(b) Wels, a mid-elevation catchment with lakes;  
(c) Ybbs, the mainstem Danube.

Annual means of air and water temperatures are correlated, but not especially strongly

A significant temperature rise of 1.5 °C on annual basis 2 °C during summer

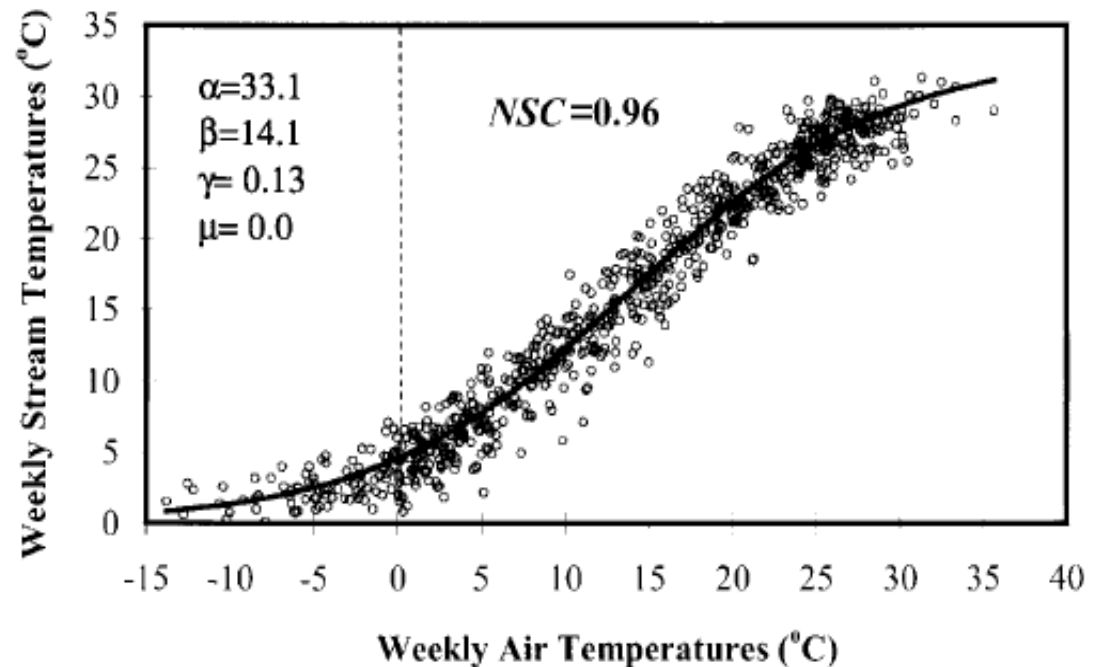
Effect appears to be magnified by presence of lakes

Other complications include heated effluent, impoundments, and abstractions



Webb and Nobilis 2007

# Modeling water temperature



$$T_w = \mu + \frac{\alpha - \mu}{1 + e^{\gamma(\beta - T_a)}}$$

Figure 1a. Weekly measured stream temperatures at the Salt Fork of the Arkansas River near Jet, OK, versus weekly air temperatures recorded at Wichita, KS. The line represents the nonlinear least squares regression between stream temperatures and air temperatures.

where:

$T_w$  = estimated water temperature

$T_a$  = measured air temperature

$m$  = estimated minimum water temperature

$a$  = estimated maximum stream temperature

$b$  = air temperature at the inflection point of the function

$g$  = measure of the steepest slope of the function

Mohseni et al. 2003

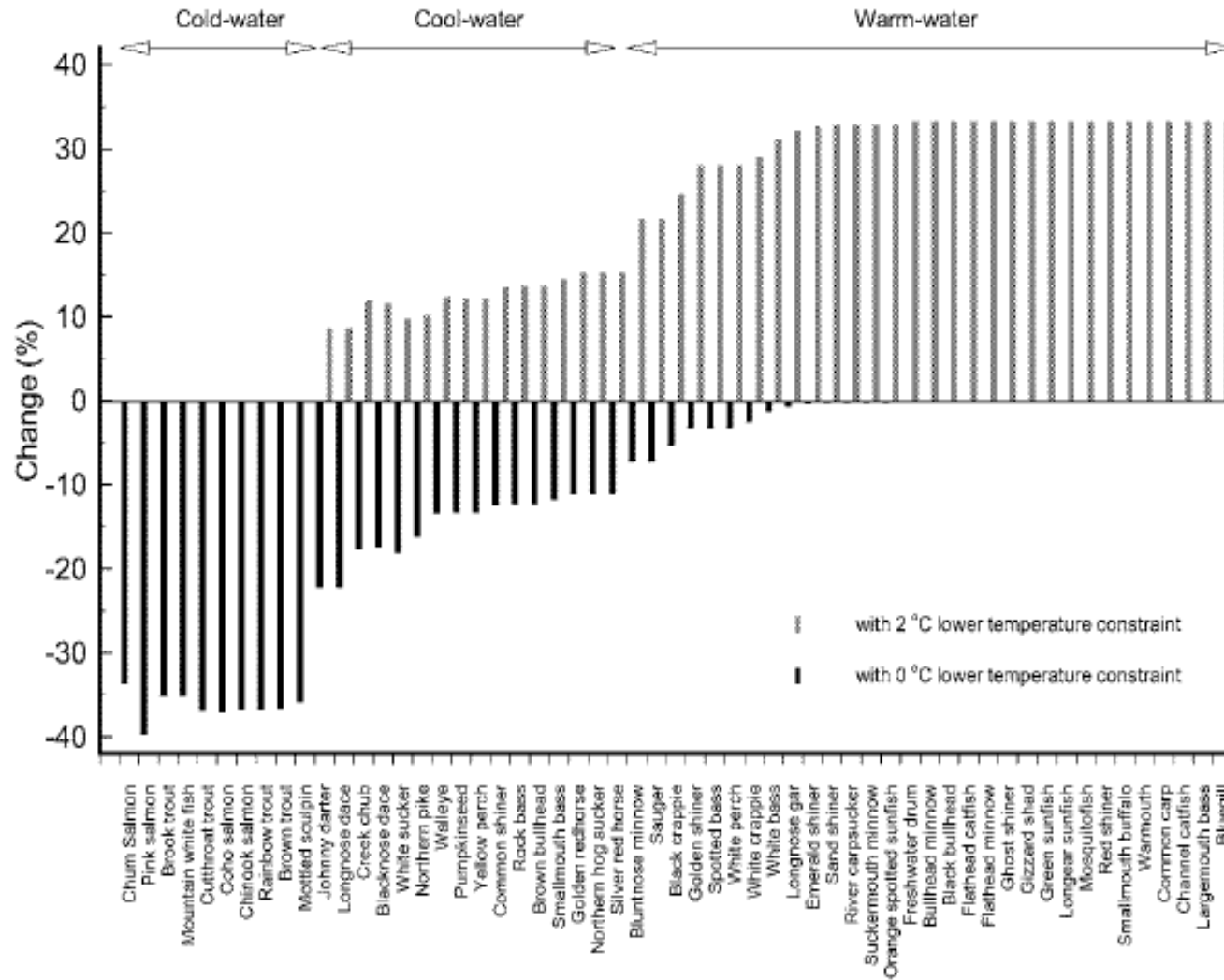


Figure 9. Changes in fish thermal habitat under the 2 × CO<sub>2</sub> climate scenario. For cool and warm water fishes lower temperature constraints are set at 0 °C and 2 °C. Changes are given as percentage of past conditions.

# Some possible concerns

- Early models assumed that stream temperature warmed linearly with air temperature (Eaton and Scheller 1996)
- Subsequent models assume a leveling off of water temperatures above 25 °C (Mohseni and Stefan 1999)
- Although air and water temperatures are strongly correlated, stream warming is primarily due to irradiance, not convective heating from the air.
- Atmospheric warming is due to heat trapping, not increased irradiance.

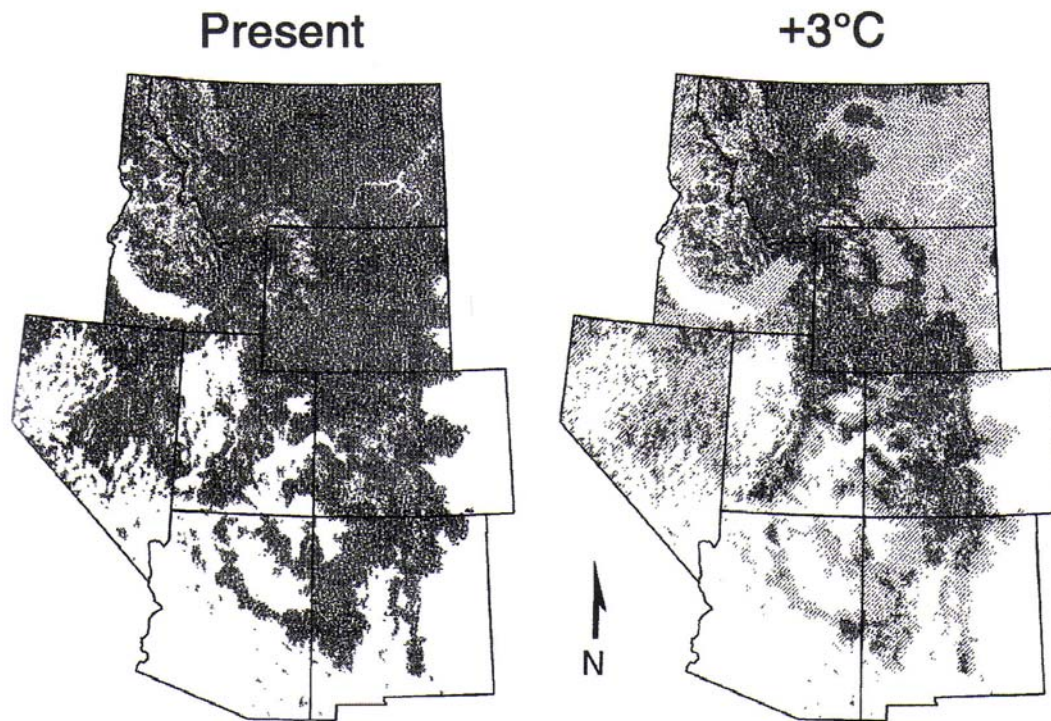
# Dispersal

- Poleward locations with suitable bioclimatic envelopes may not have suitable habitat etc.
- Catchment boundaries are natural dispersal barriers
- Stream size and habitat conditions may be strong dispersal filters
- Rivers may flow east-west rather than north-south
- Dispersal may be towards headwaters (which act like mountain-tops)



# Dispersal limitations

- Species on mountain tops must shift to higher elevation sites (if they exist)
- Species in headwaters face a similar challenge

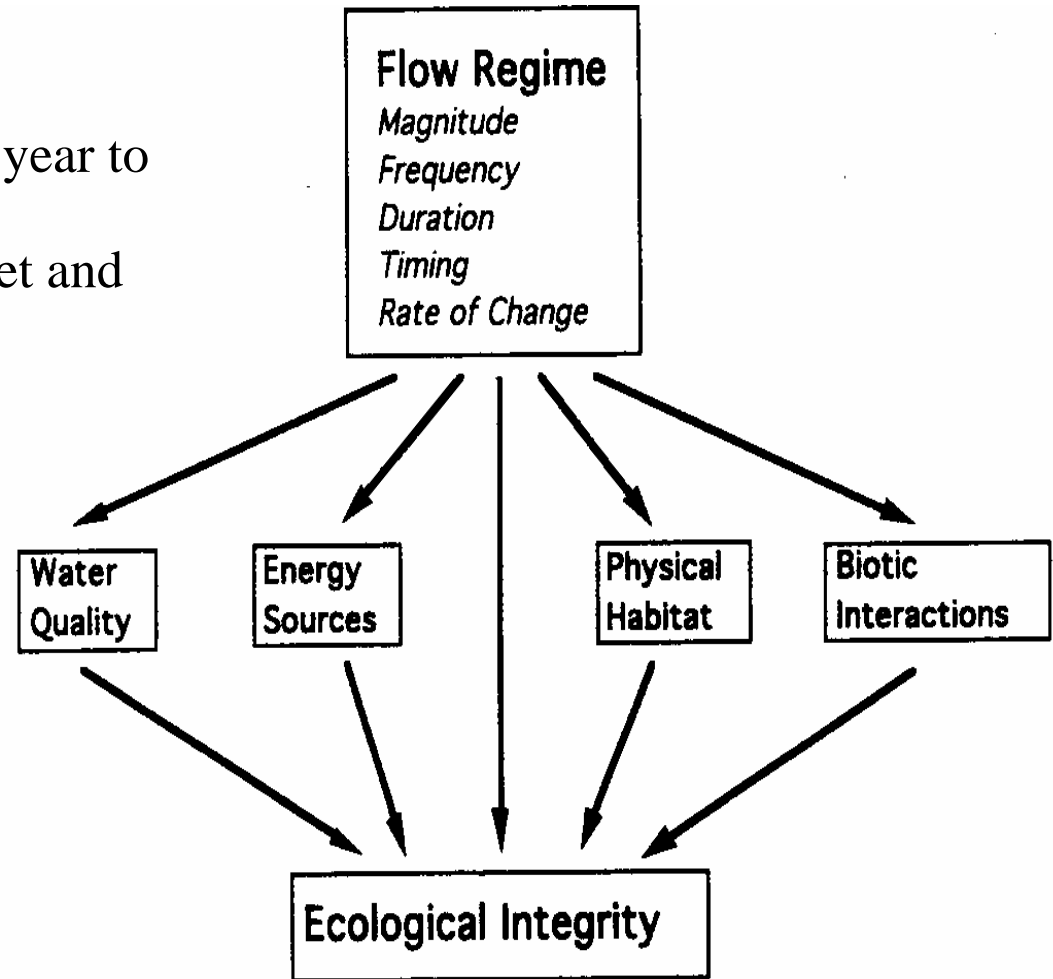


Present and potential future distribution of trout in the Rocky Mountains, given a 3 °C summer warming

Kelleher and Rahel (1996)

# Streamflow

- Varies over time
  - Day to day, week to week, year to year
  - Inter-annual variation of wet and dry years
- Varies along a river's length
- Varies with climate and geology
- Flow is viewed as a 'master variable'



From Poff et al. 1997

# The flow regime

- Magnitude of discharge
  - Amount of water moving past a point, per unit time
- Frequency of events
  - How often a flow of specified magnitude occurs
- Duration
  - The time period of a specified flow
- Timing
  - Regularity and seasonal predictability of events
- Rate of change
  - How quickly flow increases and decreases

# Controls of stream flow

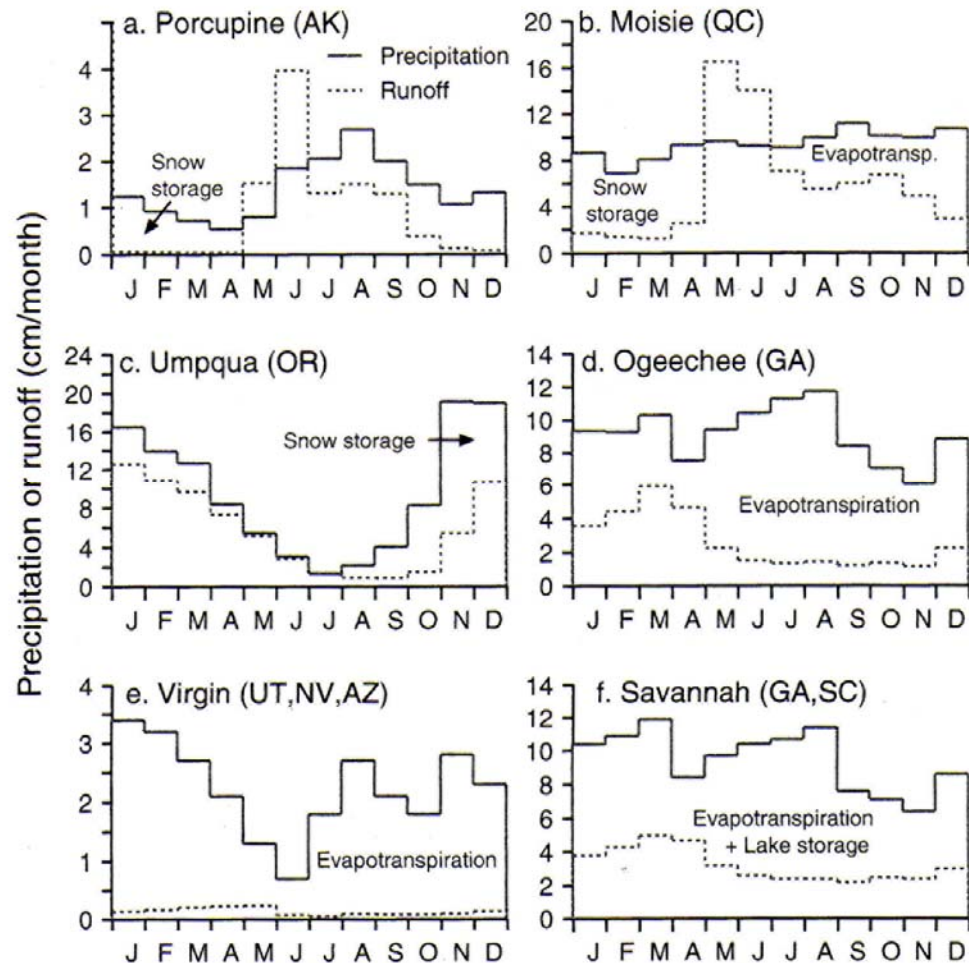
$$R = P - ET \pm S$$

R = runoff

P = precipitation

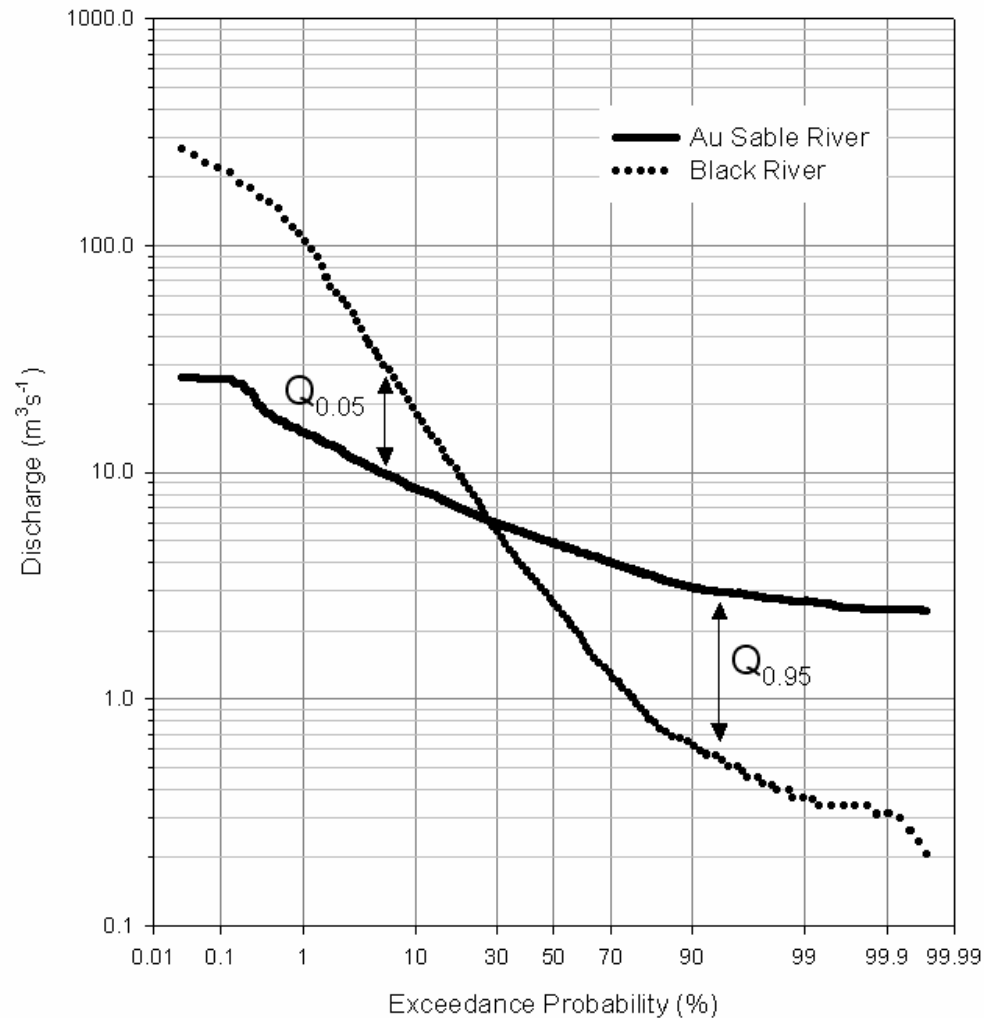
ET = evapotranspiration

S = storage



Benke and Cushing 2005

# Flashiness



Flow duration (exceedance) curves describe the percent of time that a given magnitude of flow is exceeded

$Q_{75}$  and  $Q_{95}$  are low-flow indices, exceeded 75% or 95% of the time

$Q_{25}$  and  $Q_5$  are high-flow indices, exceeded only 25% or 5% of the time

Usually based on daily flows and annual hydrograph

Shape of curve indicates stable vs flashy rivers

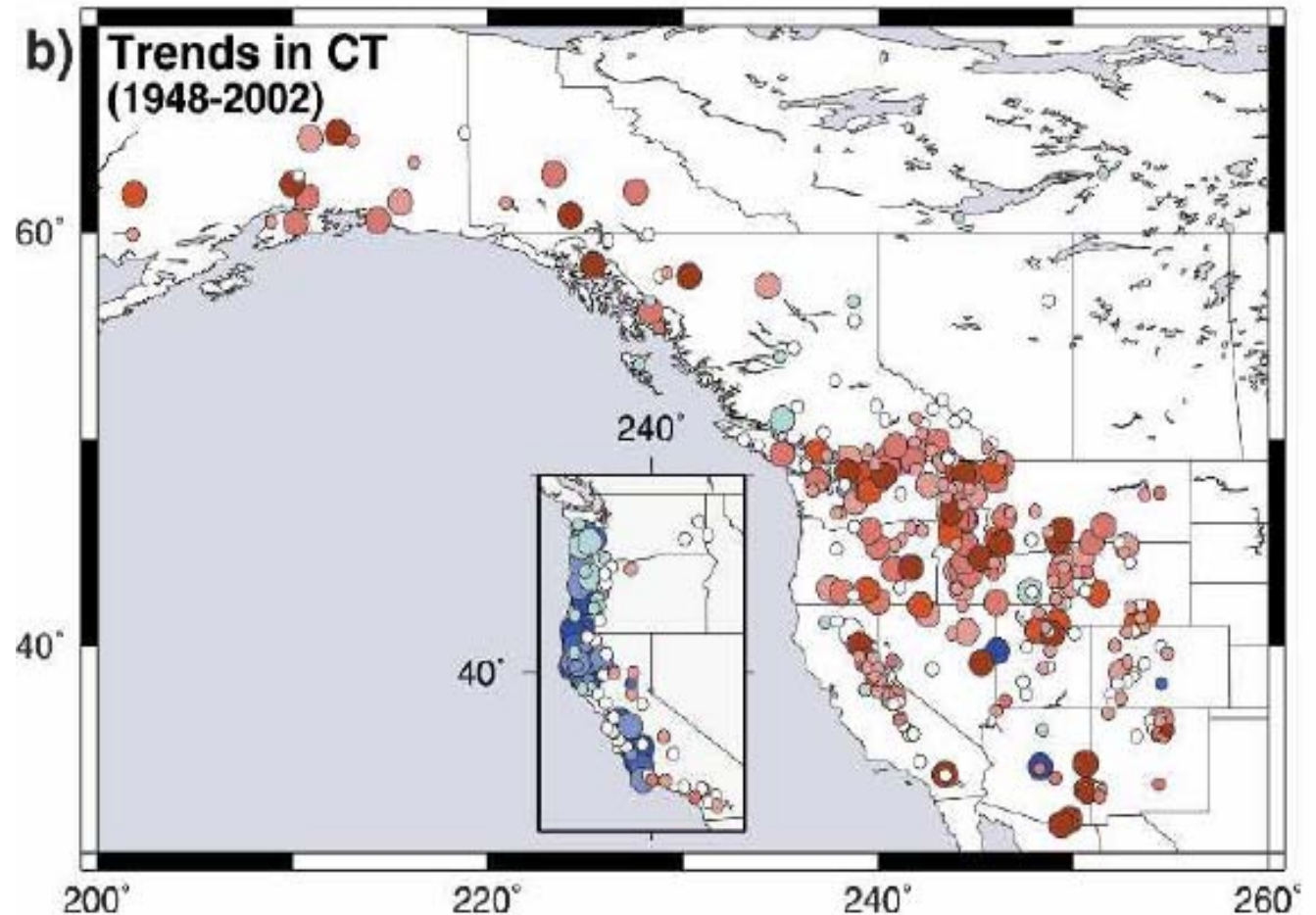
# Flow under a changing climate

- Some expectations
  - more variable and severe P
  - higher ET
  - Hard to forecast how annual and seasonal balance between P and ET will change
- More frequent floods:
  - affect export of organic matter, sediments, nutrients, channel shape, instream habitat.
  - More frequent droughts...
- Changing flow regimes
  - from snowmelt to winter rainy
  - from 1<sup>st</sup>-order to ephemeral, etc...

# Timing of streamflow

Spring pulse and center of mass of annual flow (CT) over the period 1948-2002 show earlier onset (10-30 days) throughout western North America

Partly but not completely explained by PDO



# Flow and biological assemblages

## **Hydrologically stable**

- Stable baseflow
- High predictability of daily flows

## **Hydrologically variable**

- High frequency of spates
- High variability of daily flows

Fish assemblages from more variable sites:

- exhibited generalized feeding strategies
- were associated with silt and general substrate categories
- characterized by slow-velocity species with headwater affinities
- tolerant of sedimentation

Poff and Allan (1995)



# Other factors influence flow

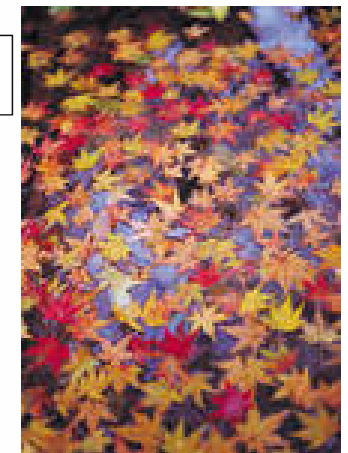
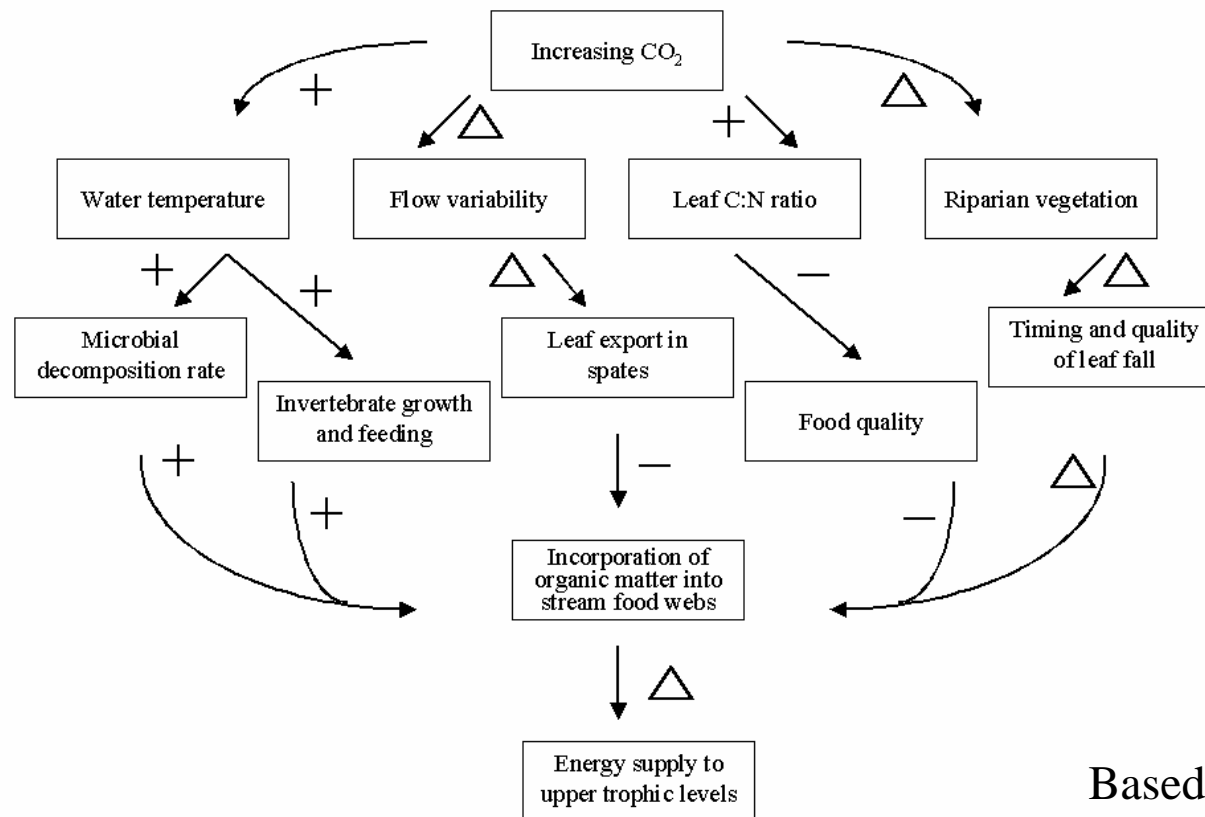
- Land-use change tends to increase flow variability
- Flow conveyances (urban, ag) increase flashiness
- Impoundments tend to reduce flow variability
- Water abstraction lowers seasonal base flows and accentuates effects of droughts

# Indirect Effects

- Basal resources
- Disturbance regime
- Species interactions
  - spread of invasives
- Water chemistry
  - Nutrient and sediment loads
- Channel morphology and dynamics
  - habitat

# Basal resources

Example: Decaying leaves (and microbes) form the base of the food web in woodland rivers. We can predict most (not all) of the likely effects of elevated CO<sub>2</sub> on this energy input,, but we cannot predict the ultimate outcome with confidence.

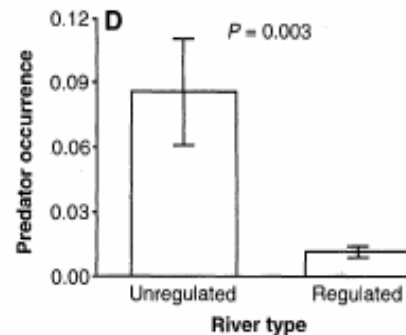
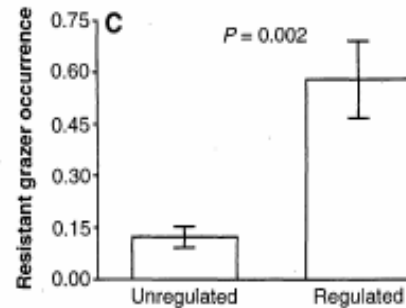
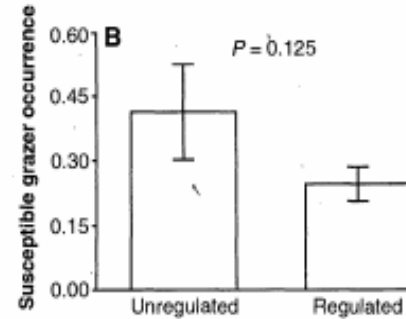
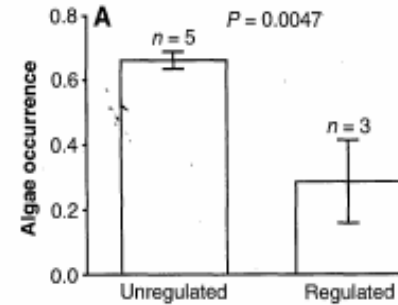


Based on work of N Tuchman and S Riers

# Disturbance

In unregulated versus regulated sections of a California stream, more energy flows to *Dicosmoecus* in regulated reaches, and to young steelhead in unregulated reaches.

- A. Visibly conspicuous algae
- B. Predator-susceptible grazers
- C. Predator-resistant grazers
- D. Predators

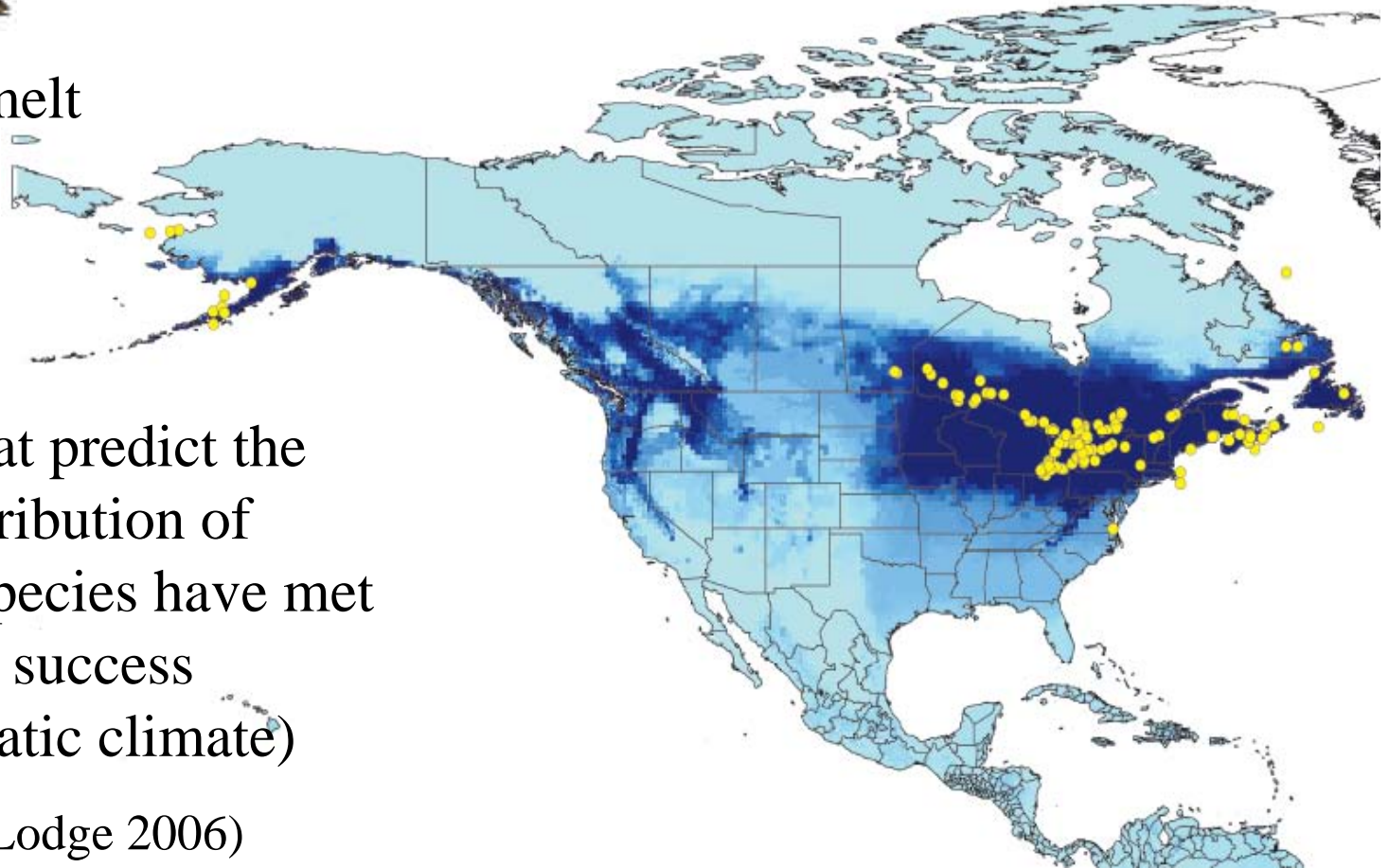


Wootton et al. 1996

# Invasive species



Rainbow smelt



Models that predict the future distribution of invasive species have met with some success (but use static climate)

(Drake and Lodge 2006)

# Interactions with other stressors

- Warming interacts with impoundments, shade, and water abstraction
- Flow variability interacts with impoundments, land use, impervious surfaces, flow conveyances
- Species assemblages and food webs are affected by pollutants, habitat loss, invasives

# Yes, we can say something...(1)

- The growing season will lengthen
- Warming will occur
- Overall productivity will increase
- Species will disperse poleward to the extent possible
- Some invasive species will re-distribute
- Assemblage composition will change

# Yes, we can say something...(2)

- Flow will become more variable, with more floods and droughts
- Water management likely will intensify
- Riparian vegetation composition will change
- Food web pathways may change



# Bioassessment implications

- Expect changes in:
  - Species composition
  - Species richness and relative abundance
- Any change is disruptive, at least for a time
- Systems already are stressed
- Re-structuring of biological assemblages may extend over centuries
- Possible (continuous) need to re-calibrate assessment tools

# Adaptation by managers

- Adjust assessment tools to changing biota
- Adjust targets/expectations
- Try to identify and manage habitats of the future for species of interest
- Try to identify and manage dispersal corridors to habitats of the future

Thank You