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Effects of Climate Change on Aquatic Ecosystems and Biological Indicators

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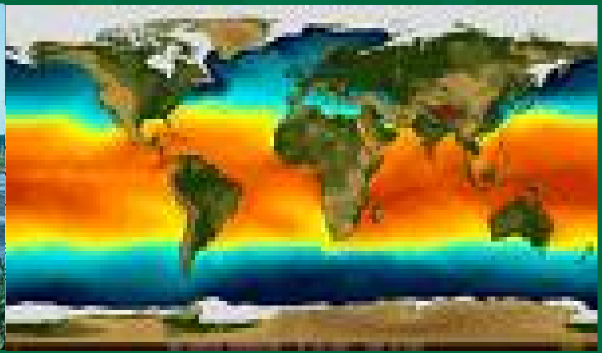
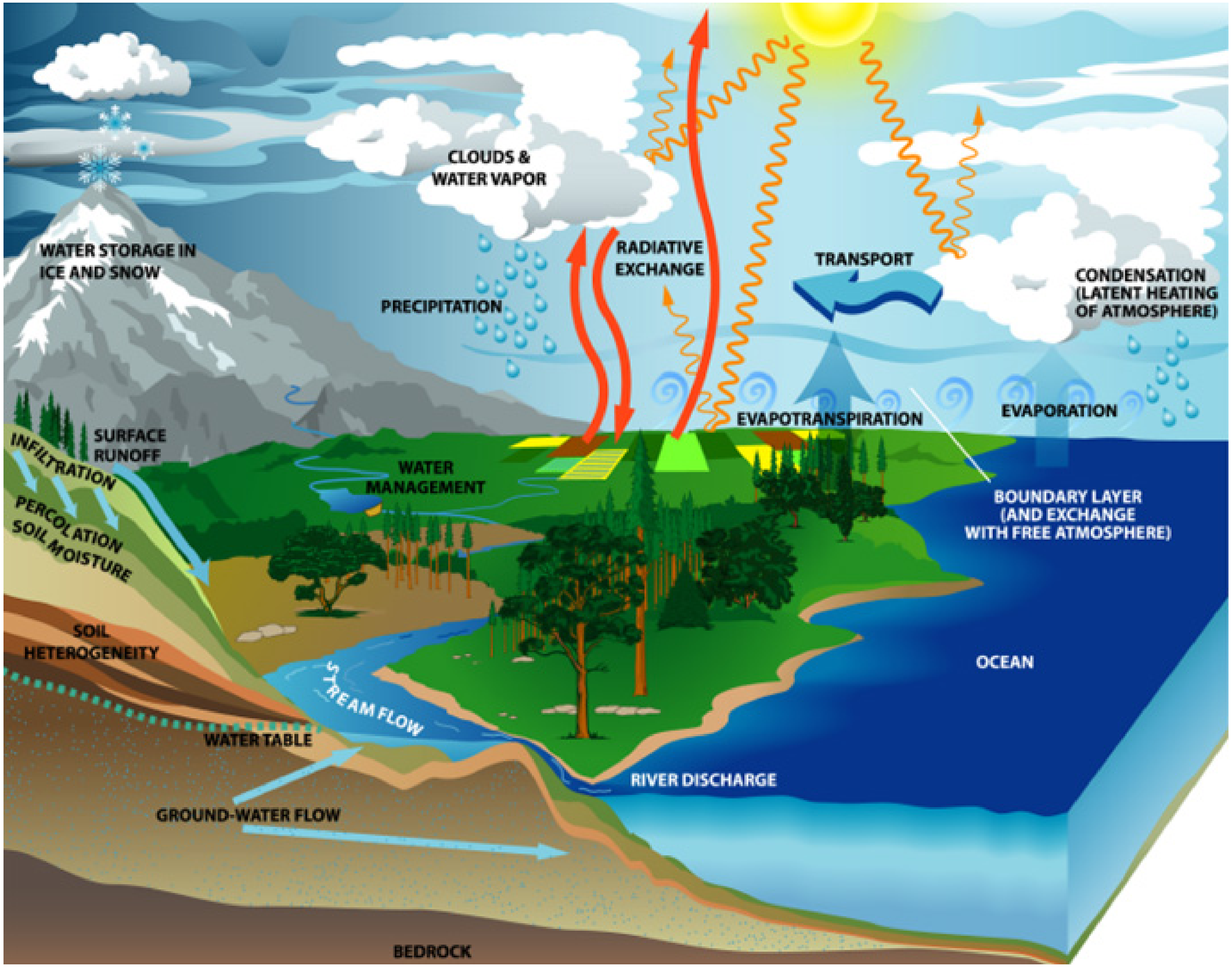
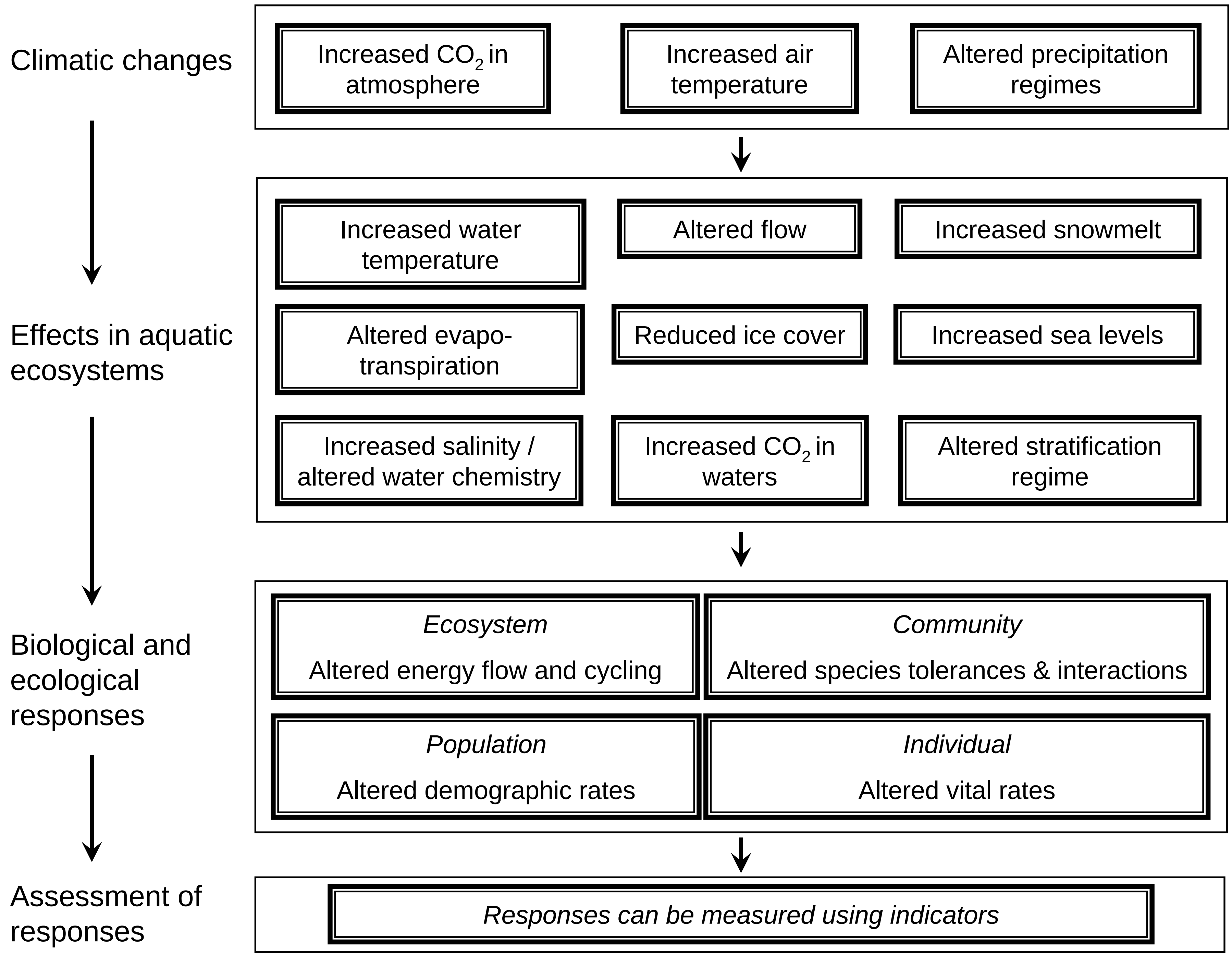
NCEA/ORD



April 10, 2008

Warming Intensifies Hydrologic Cycle





Climatic changes
Increased CO_2 in atmosphere
Increased air temperature
Altered precipitation regimes
Effects in aquatic ecosystems
Increased water temperature
Altered flow
Increased snowmelt
Altered evapo-transpiration
Reduced ice cover
Increased sea levels
Increased salinity / altered water chemistry
Increased CO_2 in waters
Altered stratification regime
Biological and ecological responses
Ecosystem
Altered energy flow and cycling
Community
Altered species tolerances & interactions
Population
Altered demographic rates
Individual
Altered vital rates
Assessment of responses
Responses can be measured using indicators

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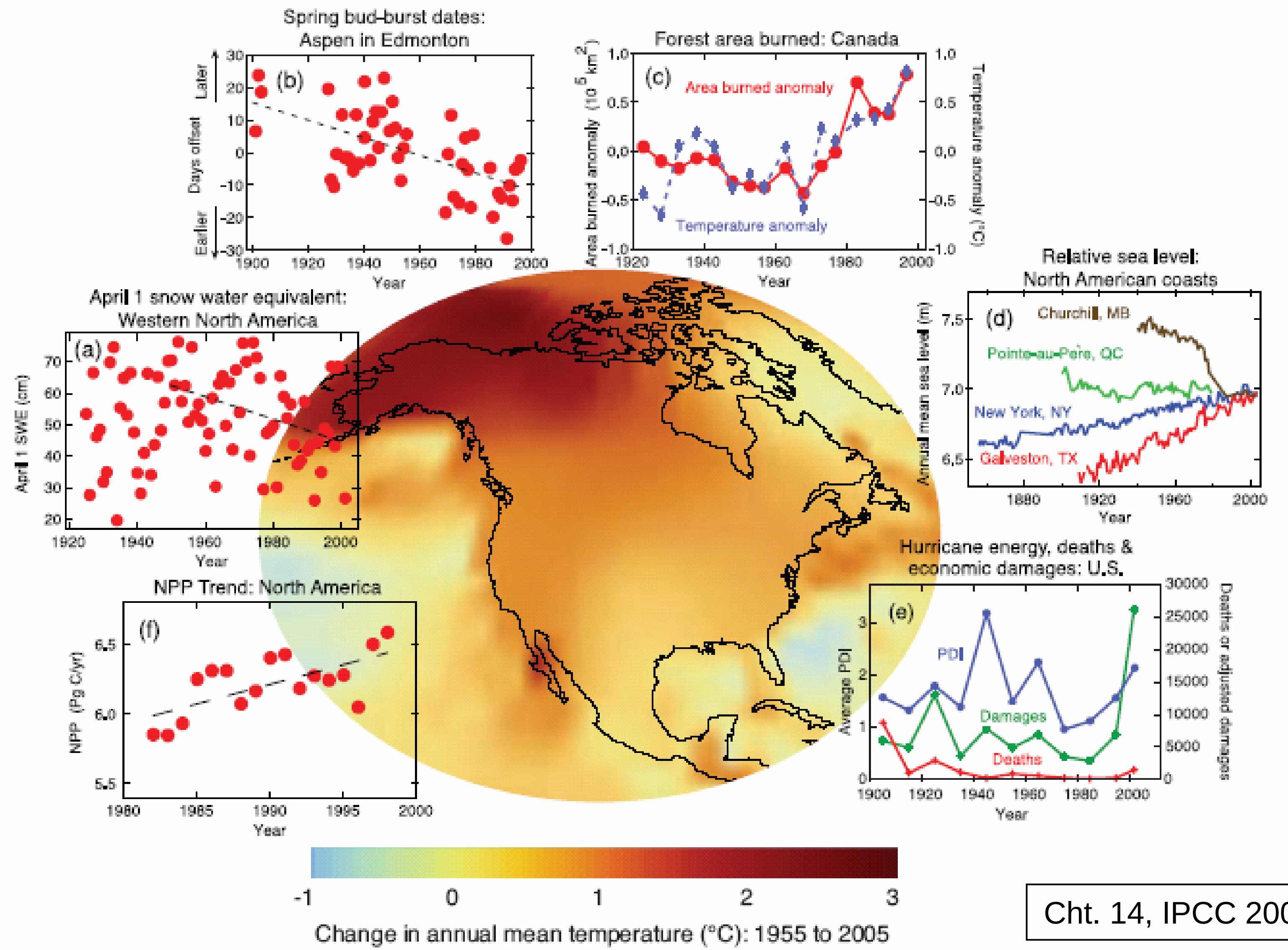
Observed Temp Trends Link to other Indicators



Cht. 14, IPCC 2007

Outline

- Climate change consequences for aquatic systems
- Effects on biological indicators
- Current and on-going research
  - Examples from Maine
- Adaptation – what can be done?



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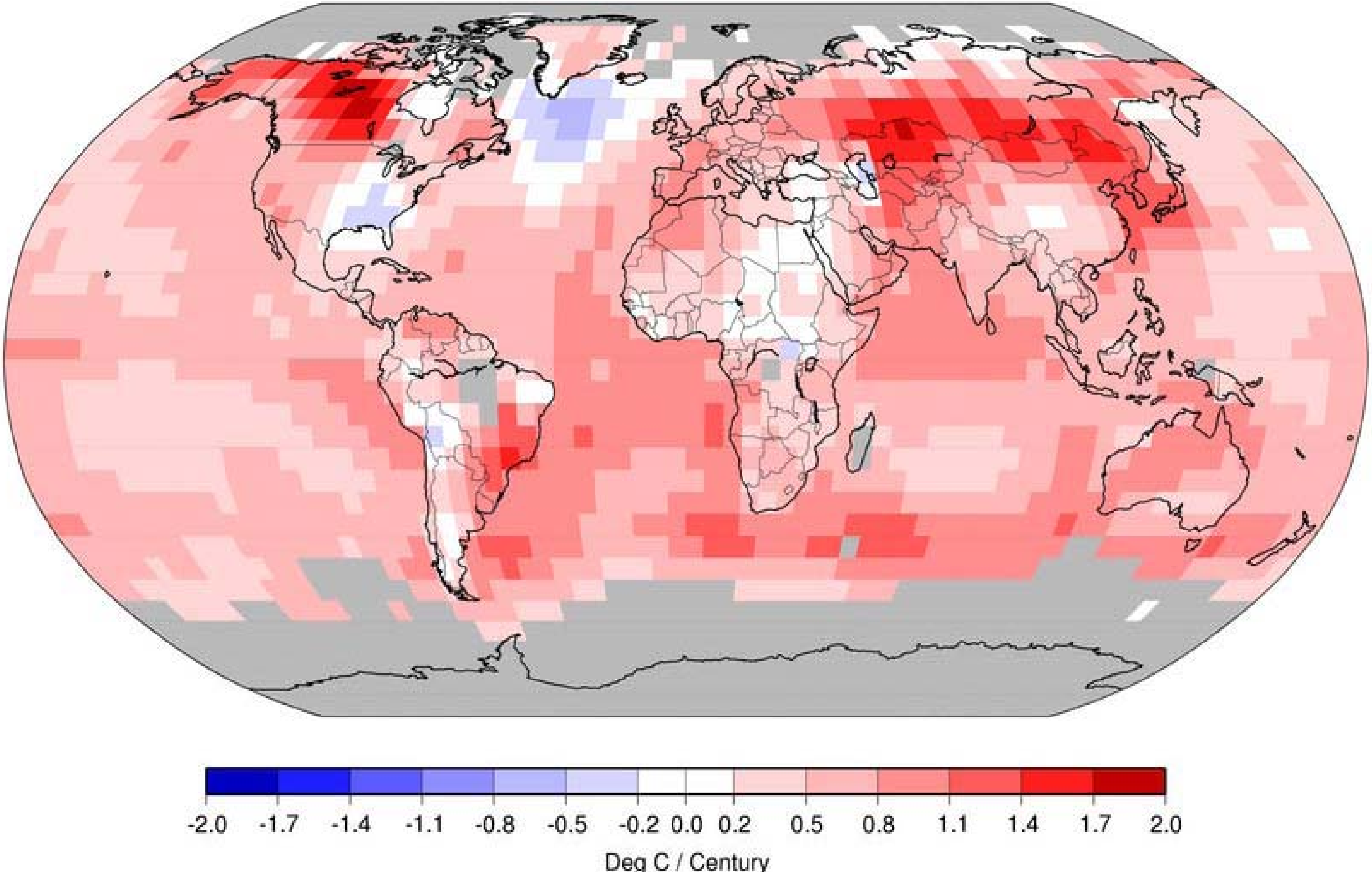
Climate Change Effects on Aquatic Ecosystems

- Changes in air temperature influence changes in ***water temperature***
- Changes in precipitation timing and amount affect ***water quantity*** and ***quality***, and ***timing of flows***
- Thermal expansion and polar melting cause ***sea level rise***
- Increasing atmospheric CO2 decreases ***pH***

Effects ***vary regionally and seasonally***

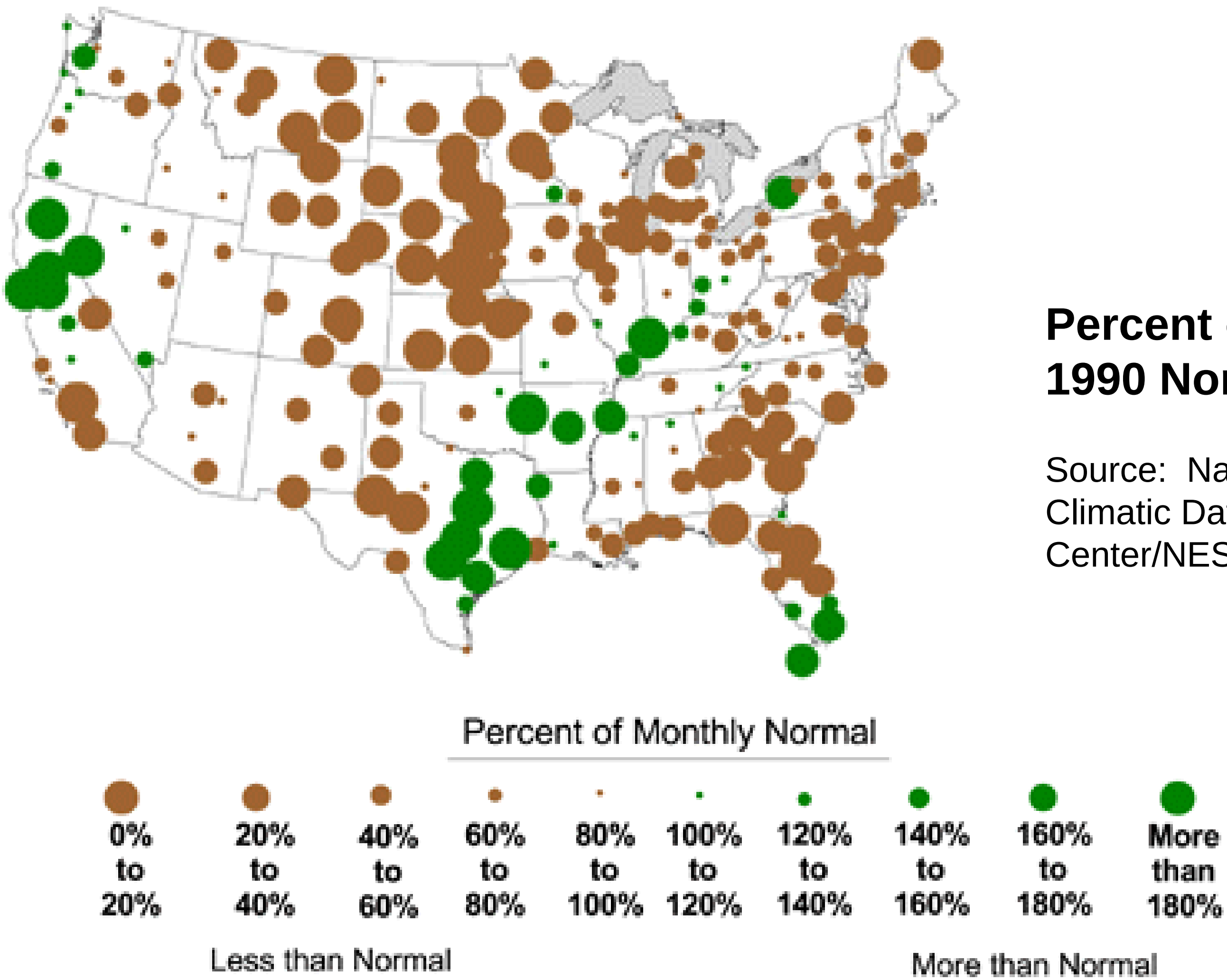
Alterations have consequences throughout ecosystem

Observed Temperature Changes 1901 - 2004



Source: Koblinsky 2006 ICLEI

December 2001 Precipitation



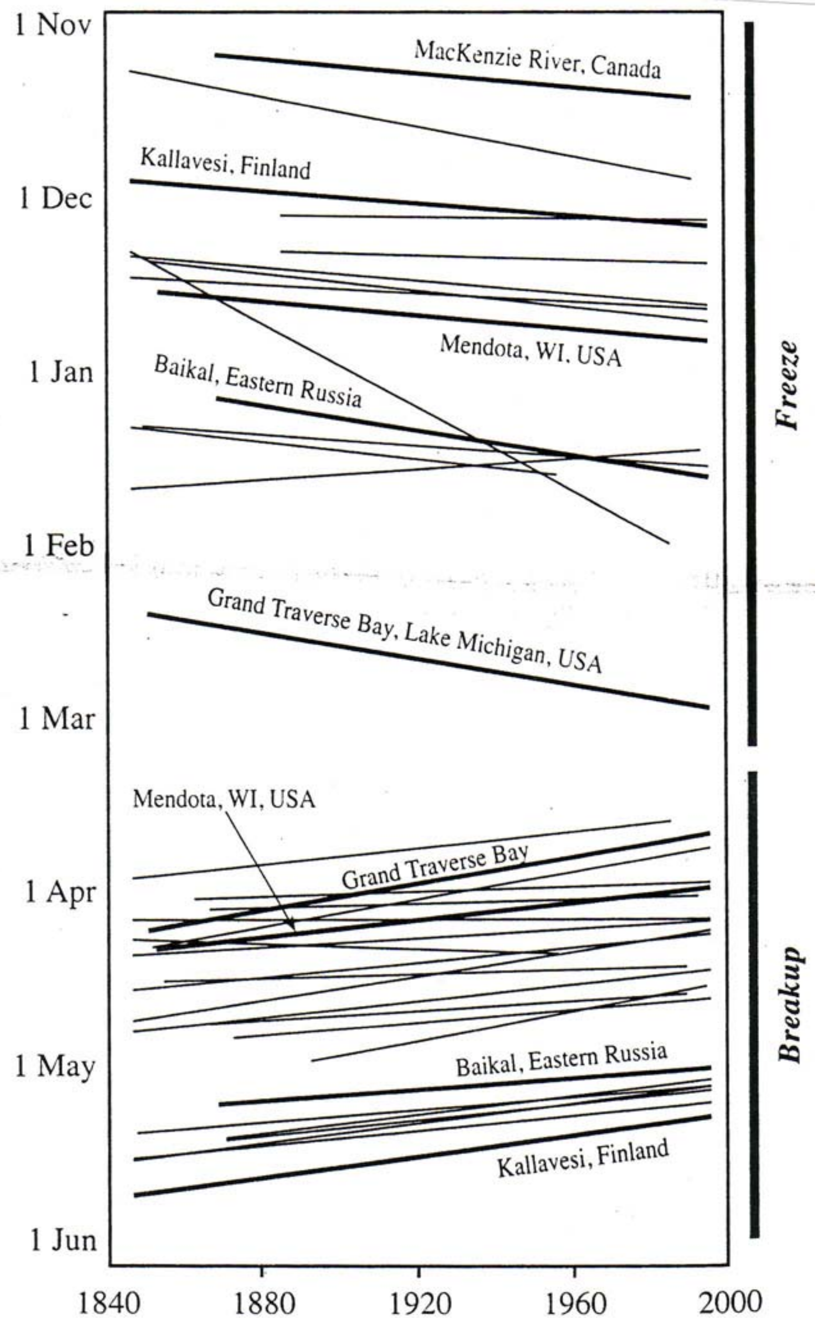
Percent of 1961 – 1990 Normal

Source: National Climatic Data Center/NESDIS/NOAA

Evidence of Stream and Lake Warming

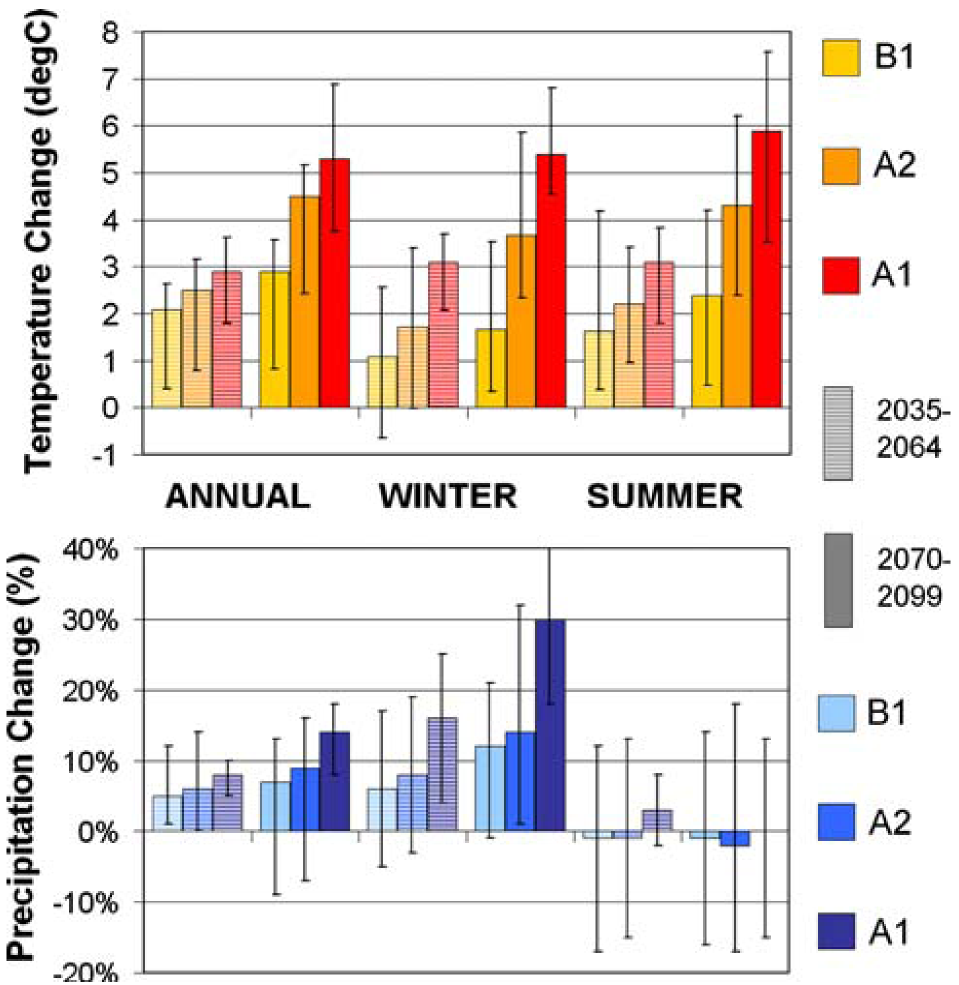
Strong evidence of changes in length of season

Freeze dates are later, thaw dates are earlier

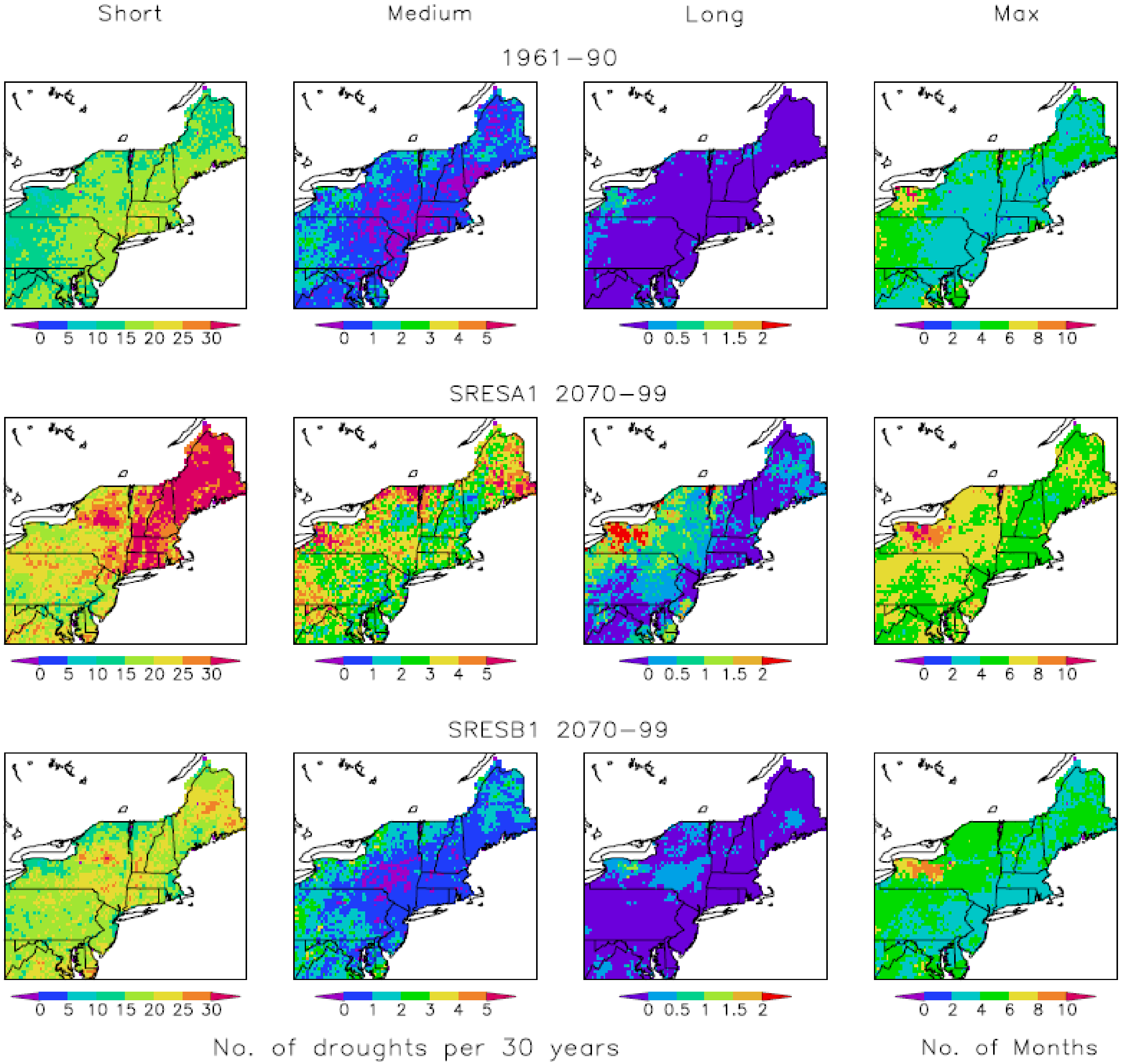


From J.J. Magnuson and IPCC reports

Projected changes in temperature & precipitation for New England



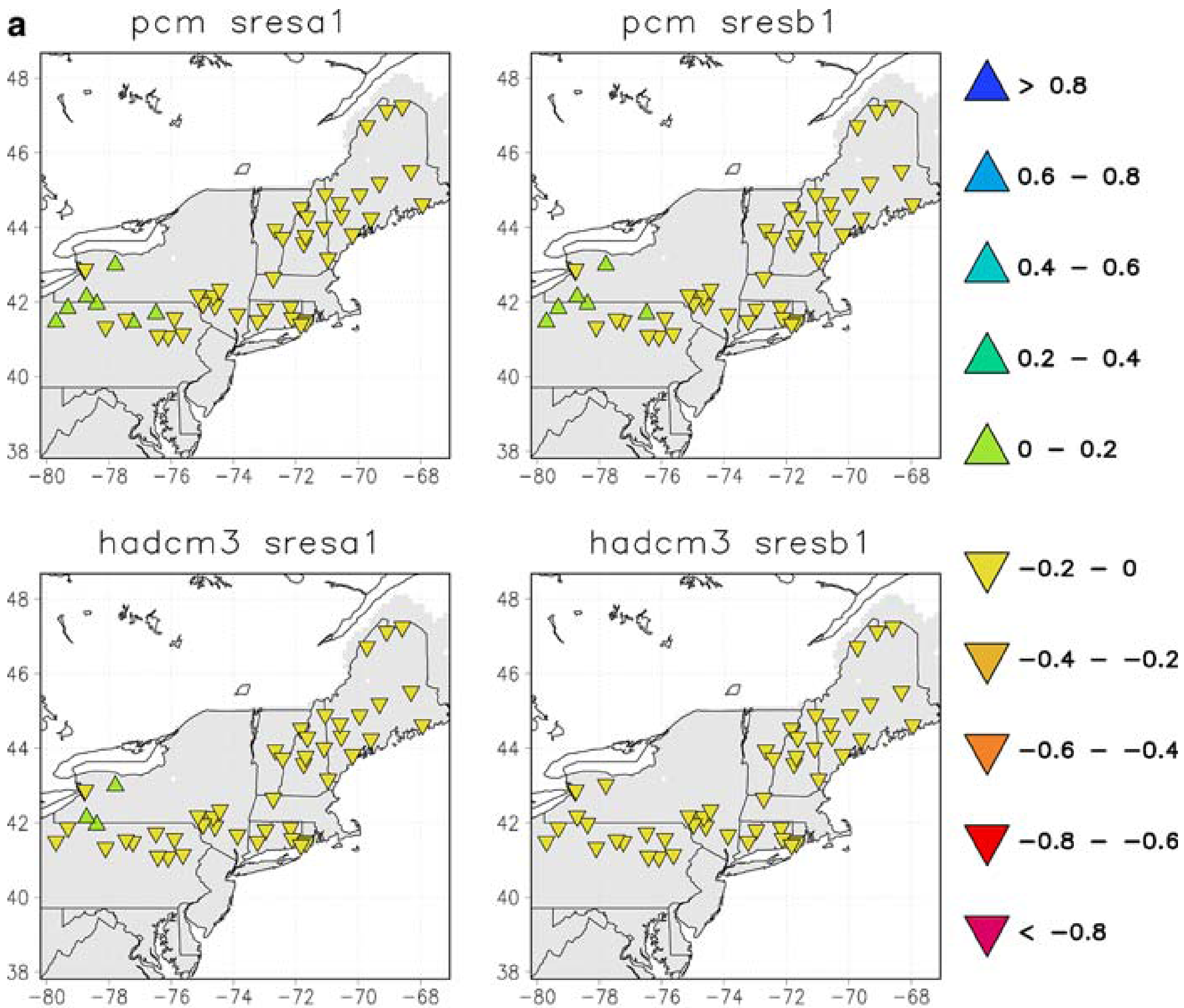
Hayhoe et al. 2007



Hayhoe et al. 2007

Projected change in probability of low flows

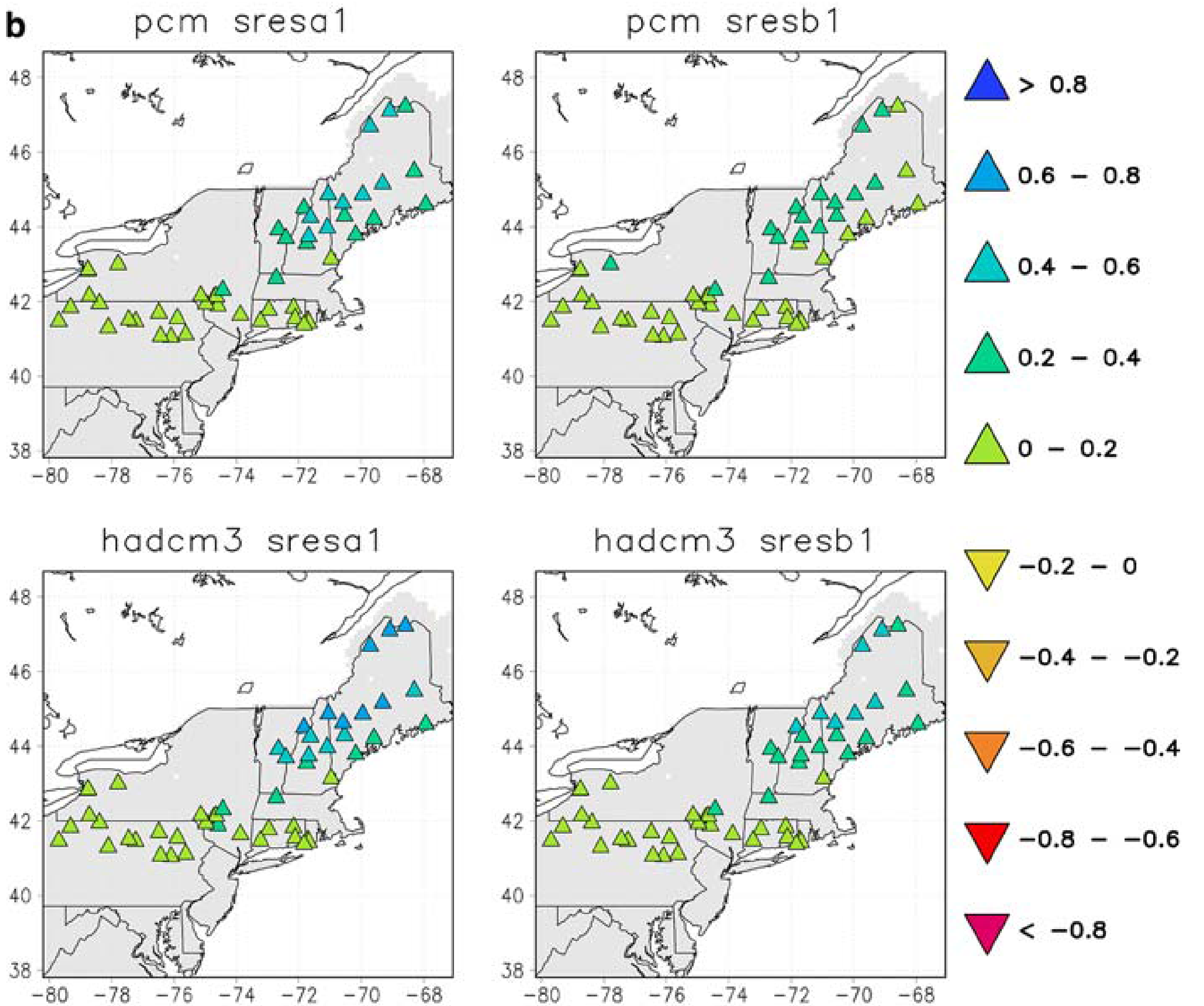
Hydrologic modeling using projected climate scenarios indicates **decreased** probability of **low flows**



Hayhoe et al. 2007

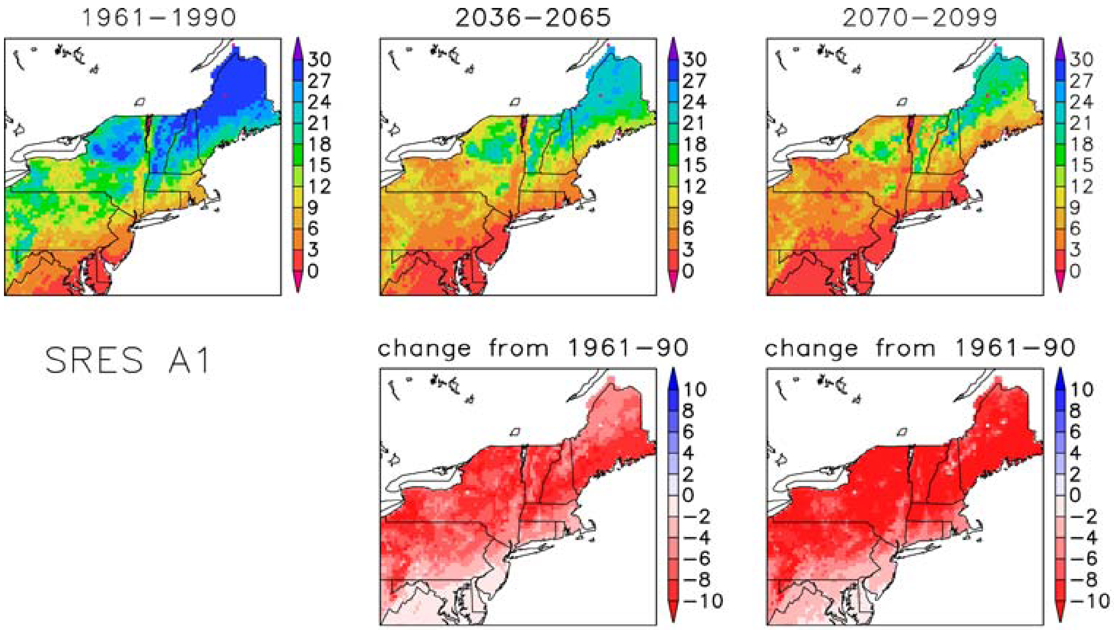
Projected change in probability of high flows

Hydrologic modeling using projected climate scenarios indicates **increased** probability of **high flows**, particularly in northern New England

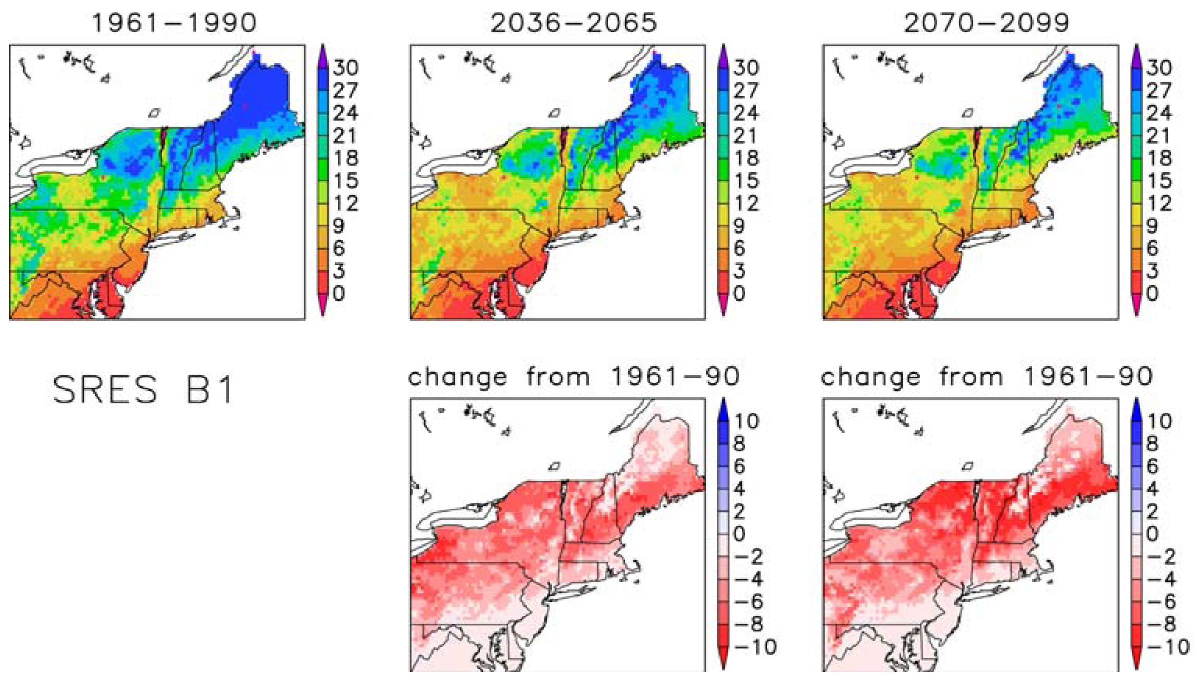


Hayhoe et al. 2007

Number of snow-covered days per month



Decreasing over time throughout New England region



Hayhoe et al. 2007

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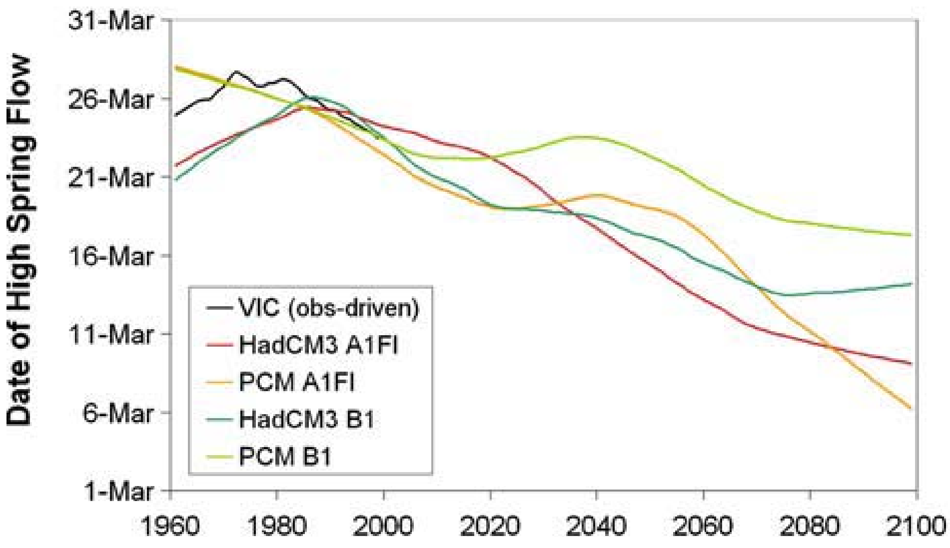
Snowmelt-driven high spring flow



Projections indicate earlier spring snowmelt

Hayhoe et al. 2007

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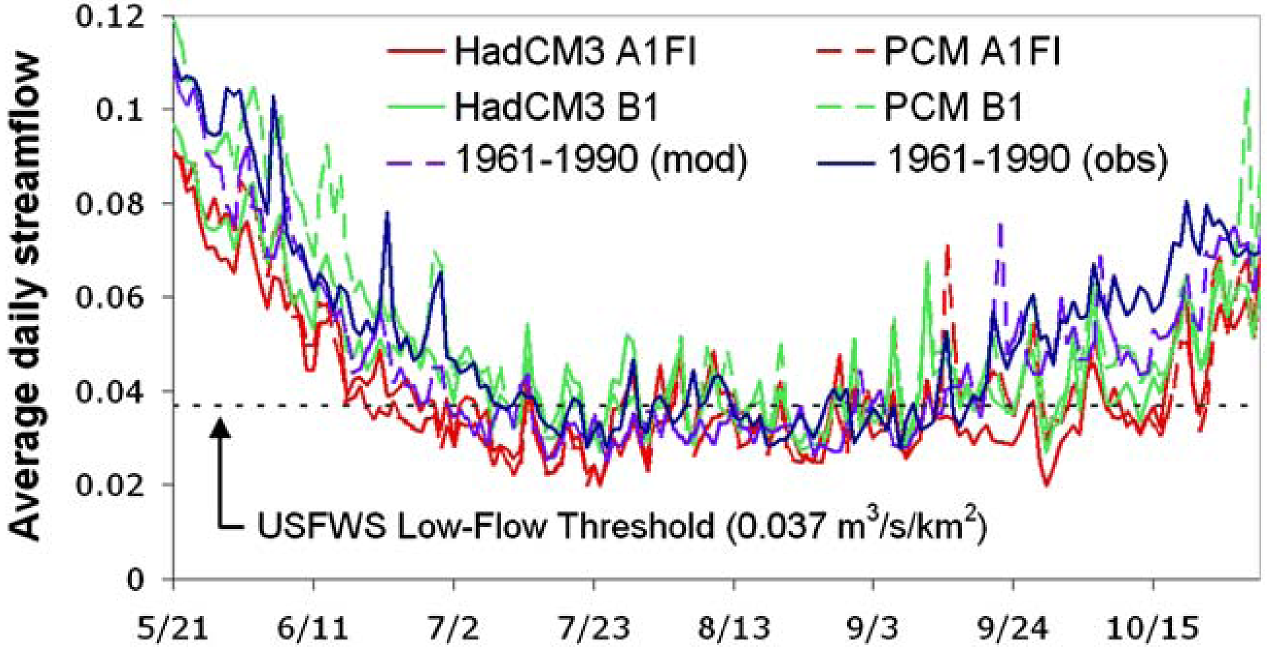
Projected changes in average daily flows



Projections indicate longer periods of summer low flows

Hayhoe et al. 2007

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Alterations have consequences throughout ecosystem

Aquatic Ecosystem Impacts

Increasing water temperatures

- Decreasing O_2 concentration, P release from sediments, increasing thermal stability, altered mixing patterns in lakes
- Earlier ice cover break up, increasing ice free periods
- Species moving up in altitude and latitude
  - Changing species composition
  - Changing seasonality & productivity of plankton
  - Changing food web interactions

Cht. 4, IPCC 2007

Climate Change & Fish Habitat in US Streams

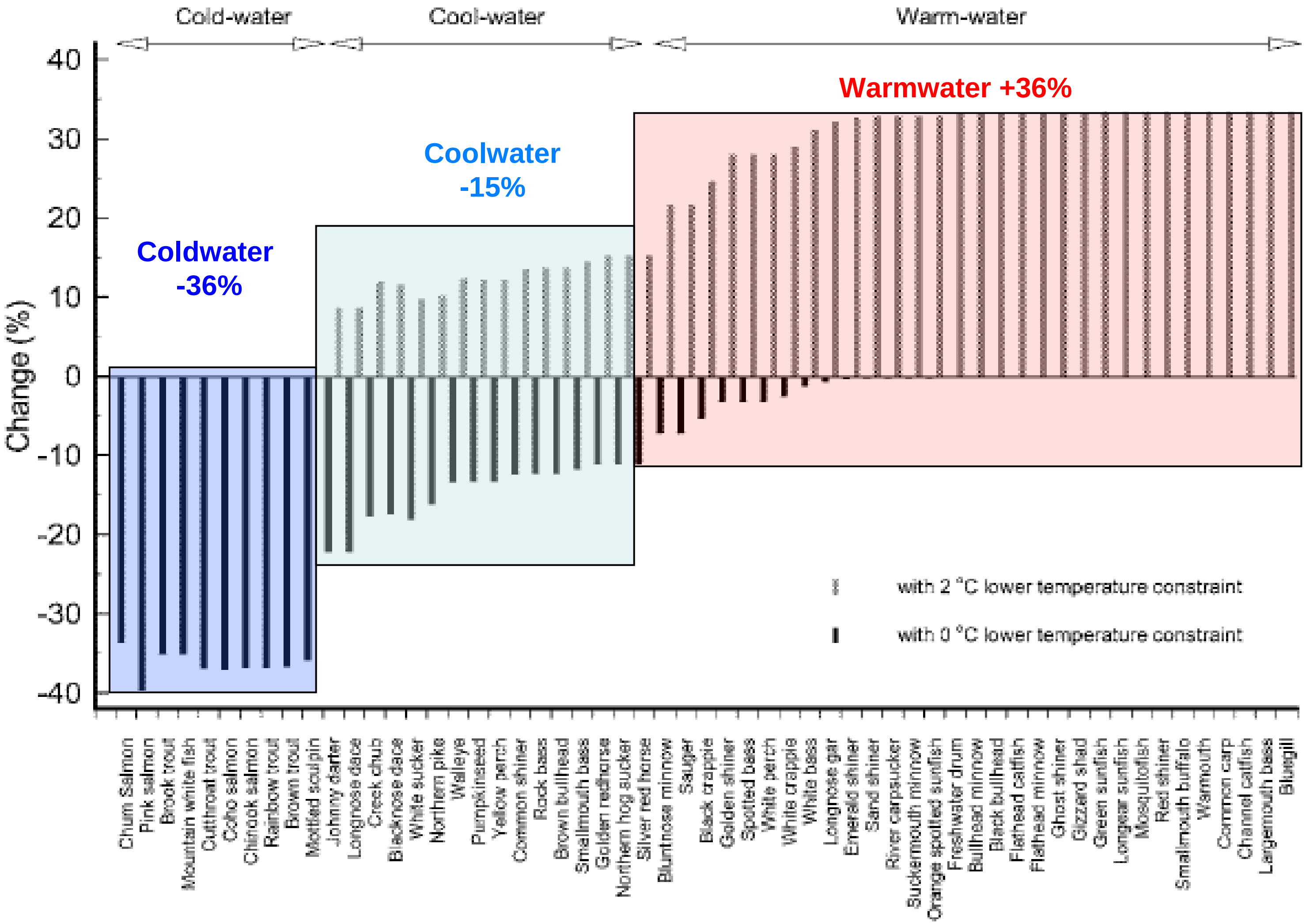
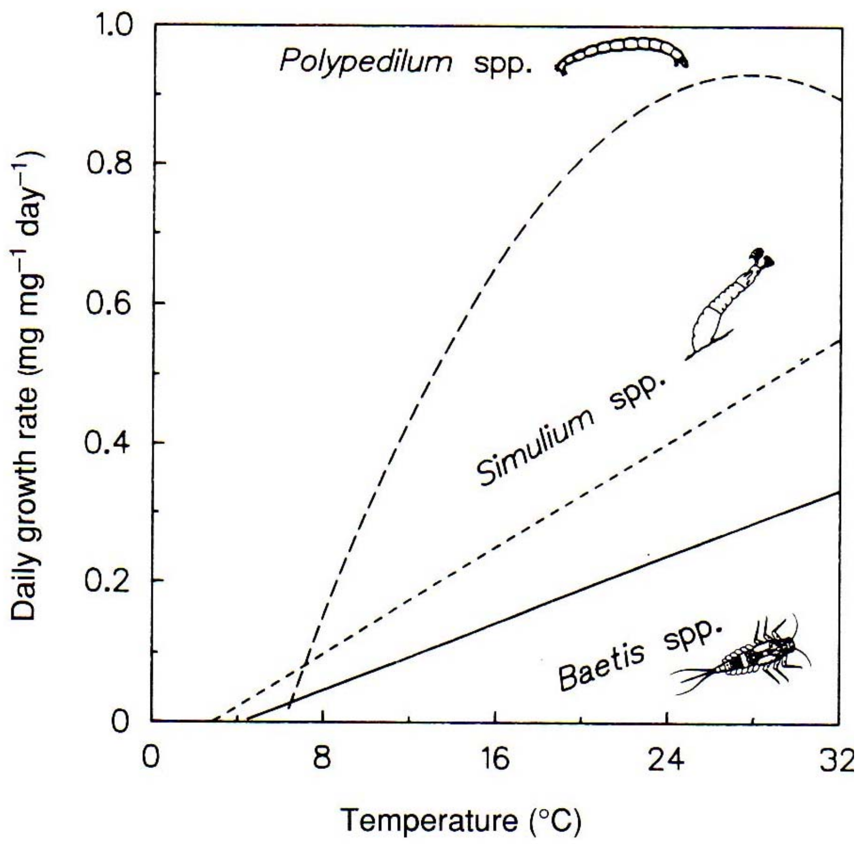


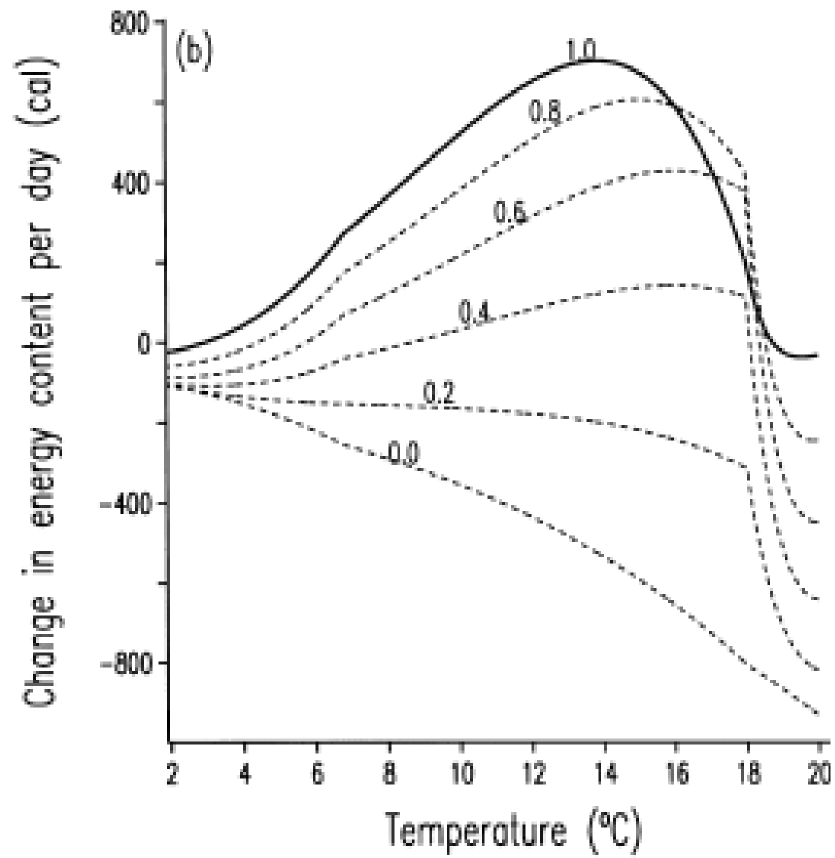
Figure 9. Changes in fish thermal habitat under the 2 × CO_2 climate scenario. For cool and warm water fishes lower temperature constraints are set at 0 °C and 2 °C. Changes are given as percentage of past conditions.

Mohseni et al. (2003)

Increased Biological Production



Benke 1993



Elliott and Hurley 2000

Land Use Effects

- Hydrologic alteration
- Sedimentation
- Nutrient enrichment
- Contaminant delivery
- Riparian clearing/canopy opening
- Loss of large woody debris

Pathways

Impacts

Allan, J.D. 2004. Landscape and riverscapes: The influence of land use on river ecosystems. *Annual Reviews of Ecology, Evolution and Systematics* 35:257-284.

Multiple factors influence flow

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

Climate Interacts 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, invasive species

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Is climate change a new threat?

- Most of the impacts of climate change are similar to other existing stressors, which are being dealt with by current water resource decision-making.
  - Higher high flows, lower low flows – similar to effect of urbanization
  - Warmer water temperatures – similar to effect of thermal effluents
  - Sea level rise effect on coastal community water supplies – similar to effect of extraction-driven salt water intrusion

Asam, Freed, Scheraga, Allan, Loughran
AWRA Conference Nov 12, 2007

Climate and Land Use Change Interaction

- High flows
  - Land use likely to dominate signal
- Low flows
  - Climate likely to dominate signal

Climate change

Urban growth

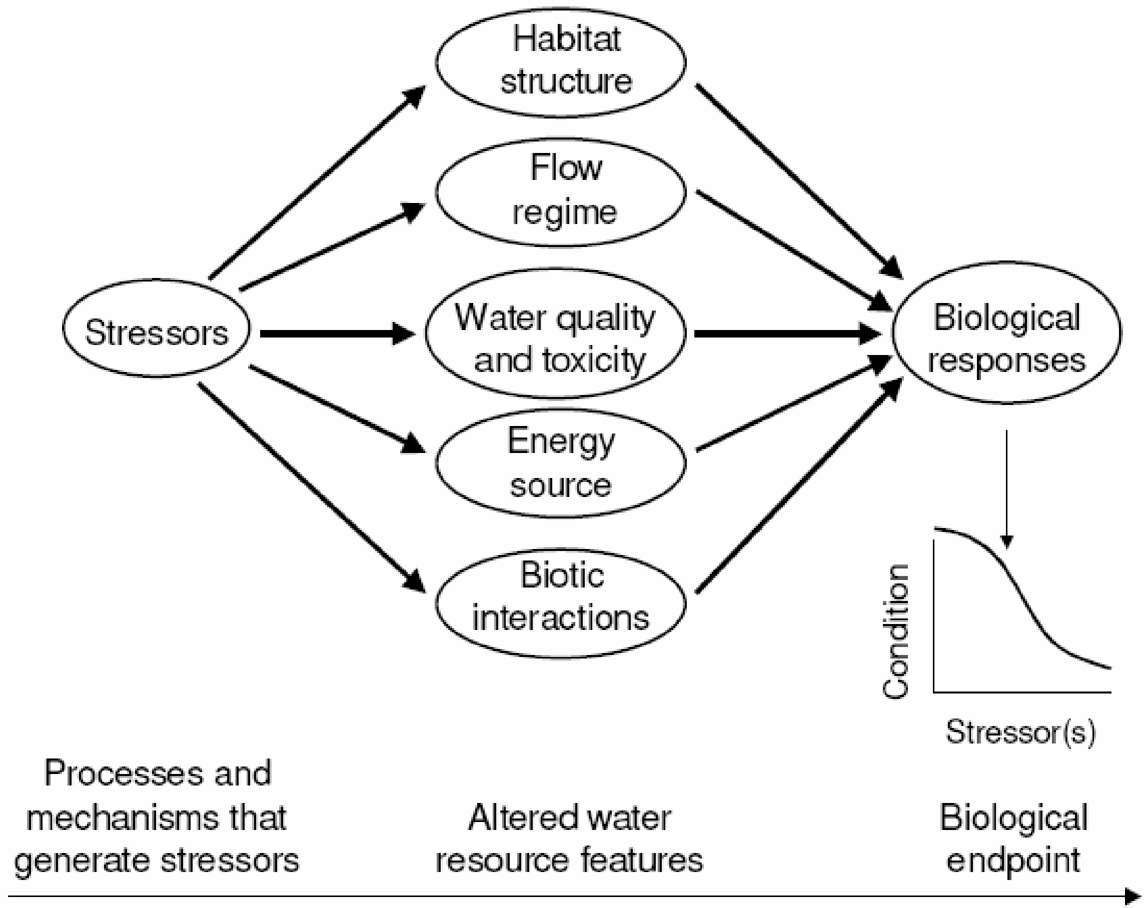
Agriculture

Timber harvest

Mining

Atmospheric pollution

Water-born contaminants



The causal sequence from stressors and their sources through the five major water resource features to the biological responses, i.e., the biological endpoints.

TALU doc 08-31-05 Fig 1-2

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How do we continue to measure impairment due to existing stressors in a changing climate?





Climate Change & Bioassessment Programs

- Additional stressor on ecosystem
- Affects both reference & non-reference sites
- Current indicators may be confounded by climate change effects on ecosystems
- Bioassessment program management goals
  - Difficult to establish goal if baseline is changing
  - Or goals may be impossible to meet





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How do existing biological indicators respond to climate change?





Project Overview – Phase 1

- Conducted literature review of biological indicators used in bioassesment programs
- Reviewed state biocriteria programs
- Developed framework to categorize biological indicators according to sensitivity to climate change
- Conducted case studies on effects on reference and non-reference sites and monitoring strategies
- Held workshops for biocriteria managers (Spring ’07 & ’08)
- Final report on preliminary analyses to be released April 2008

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Summary of Report Findings

- Biological indicators can be categorized into three broad areas
  - Sensitive to CC, sensitive to CC and other stressors, and insensitive to CC
- Mechanisms by which CC affects indicators can be used to define "sensitive to CC"
- Power to detect CC effects using monitoring data from bioassessments will vary depending on magnitude of CC variable, species loss rate, population variance, and degree of confidence specified
- CC may affect reference sites disproportionately, narrowing gap between reference and non-reference
- Potential increase in variability in condition among reference sites may impede a state's ability to detect impairment

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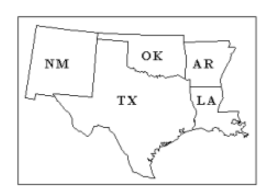
Next Steps – Phase 2

- Evaluate and understand how current indicators and indices respond to climate change regionally through pilot studies
- Develop climate sensitive and insensitive indices
- Use historical data to examine trends at reference sites linked to climate variables
- Use data to project potential effects from CC
- Case studies on land use change interactions
  - Examine vulnerability of reference sites
  - Examine similarities and differences in responses of indicators to urbanization vs. climate change

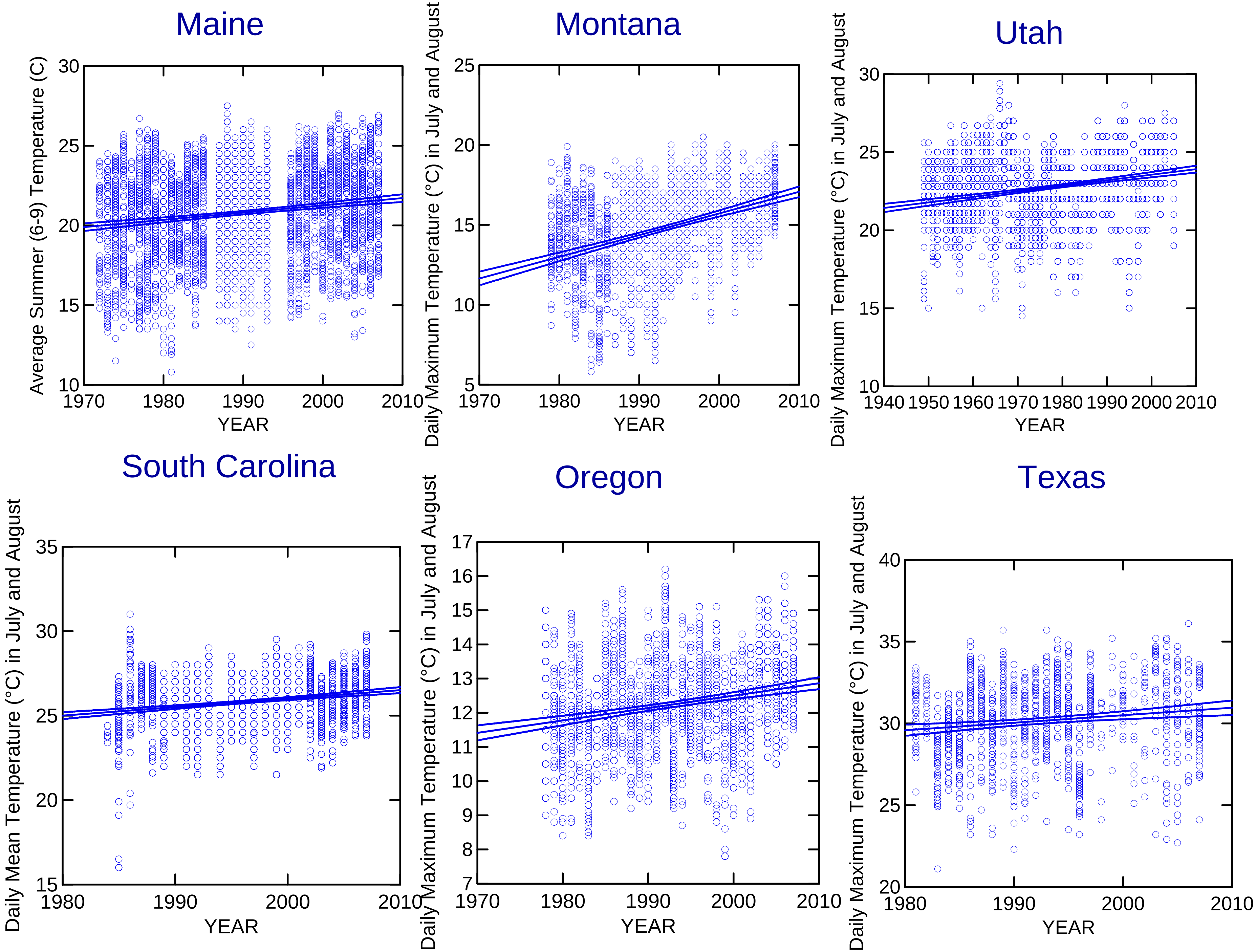
Pilot Studies

- In-depth studies focusing on needs of state programs, incorporating inputs from last workshop
- Focus on detailed evaluation of potential indicators
- Taxa traits associated with climate change responses
- Regional variation among indicators and traits
- Test for trends among state databases to test taxa and functional group hypotheses
- Categorize species according to sensitivities and responses
- Develop indices

Evaluating bioassessment data from:

- Maine
- Utah
- Ohio
- North Carolina (and South)

- Length of record
- Repeat sampling (in addition to probabilistic)
- Corresponding environmental data
- Status of data (e.g. QC)
- Expectations for regional climate change effects



Maine
Average Summer (6-9) Temperature (C)
YEAR
Montana
Daily Maximum Temperature (°C) in July and August
YEAR
Utah
Daily Maximum Temperature (°C) in July and August
YEAR
South Carolina
Daily Mean Temperature (°C) in July and August
YEAR
Oregon
Daily Maximum Temperature (°C) in July and August
YEAR
Texas
Daily Maximum Temperature (°C) in July and August
YEAR

Dataset screening

- Locate data from reference sites
  - Maine ‘AA’ and ‘A’ rated sites
- Consistent collection methods
- Changes in taxonomy and level of identification
- Consistent sub-sampling methods
- Consistent sampling periods
- Locate sites at or near USGS gauges

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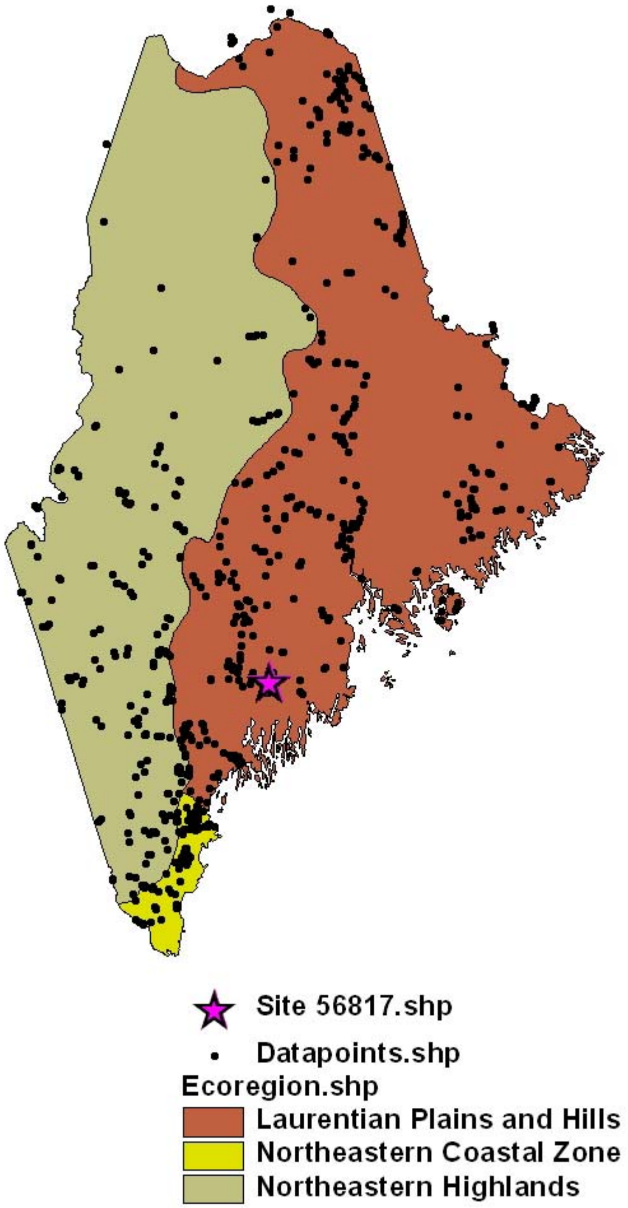
SITE 56817 – SHEEPSCOT RIVER - STATION 74

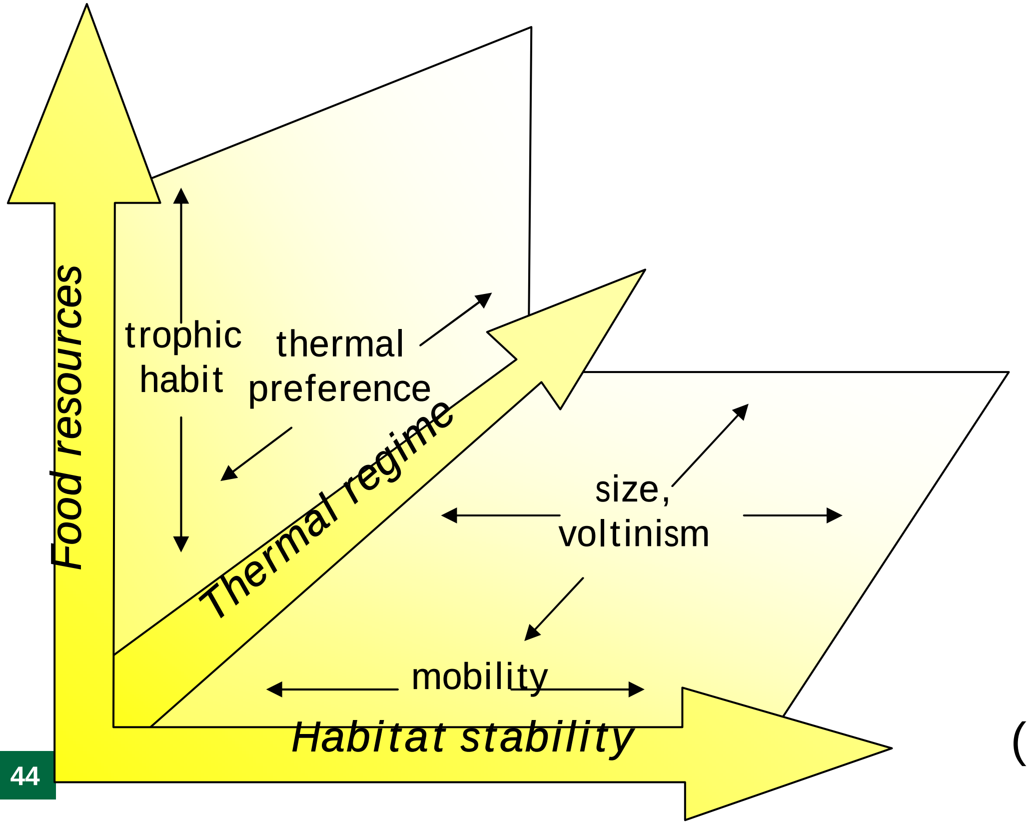
ABOVE RT. 126 BRIDGE AT USGS GAUGE

- 4th Order, Wadeable, Drainage Area 145 Sq. Mi.
- Reference Condition 'AA', but not 'pristine; some non-point source pollution.
- In the Central Interior Biophysical Region and the Laurentian Plains and Hills Ecoregion
- Annual biological monitoring, 1984-2006 (=23 years).



Key Environmental Drivers
- Habitat structure & dynamics
- Temperature
- Food resources

Species responses
- What traits should vary "mechanistically"?



Trait responses along environmental gradients

(Poff et al., JNABS, 2006)

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Categories of Indicators

	Insensitive to Climate Change	*Sensitive to Climate Change*	*Sensitive to Climate Change and Other Stressors*
Indicator	Warmwater fish	Fish community composition	Salmon egg to fry survival
Response	No change in majority of range	Cold- and coolwater fish species decline, warmwater fish species increase	Decreased survival due to increased turbidity from sediment input due to increased precipitation and/or land use change

What Defines Climate-Insensitive?

- Ecological events not cued to temperature
- Species is tolerant of broad temperature range
- Tolerant of wide range of hydrologic conditions
  - High flows or low flows
  - High variability in flow
  - Variation in salinity

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What Defines Climate-Sensitive?

- Ecological events cued to temperature
- Species exists in narrow temperature range
- Intolerant of certain hydrologic conditions
  - High flows or low flows
  - Saltwater intrusion






Climate-Sensitive Traits

- Phenology (timing of emergence, reproduction, flowering, etc.)
- Longer growing season (number of reproductive periods)
- Life stage-specific
- Temperature sensitivity
- Hydrologic sensitivity






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Macroinvertebrate Traits and Trends

- Temperature preferences/sensitivities estimated from data, including weighted average and other modeling results from Oregon, California, Idaho, and current pilot studies
- Existing literature (e.g., EPA, USGS traits DB)
- Refine with testing of trends from these data bases

Database will be made available

Limitation: there is a large amount of data on some species and virtually none or only scarce information for others

Other traits may be useful explaining responses to climate change

- Dispersal Ability
- Distribution
- Voltinism
- Timing of Emergence

Potential Cold-Water Indicator Taxa

- **Rhyacophila** (Trichoptera)
- **Parapsyche** (Trichoptera)
- **Ameletus** (Ephemeroptera)
- **Epeorus** (Ephemeroptera)
- **Pteronarcys** (Plecoptera)
- **Perlodidae** (Plecoptera)
- **Micropsectra** (Chironomidae)
- **Brillia** (Chironomidae)

Potential Warm-Water Indicator Taxa

- **Pseudochironomus** (Chironomidae)
- **Pentaneura** (Chironomidae)
- **Cheumatopsyche** (Trichoptera)

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Level of taxonomy

Species within a genus with differing preferences/requirements

Baetis (Ephemeroptera)

Cold water preference
- *Baetis bicaudatus*
- *Baetis parvus*

No strong temperature preference

Most Baetis fall into this category. A few examples are:
- *Baetis tricaudatus*
- *Baetis brunneicolor*

Warm water preference
- *Baetis australis*
- *Baetis intermedius*

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Adaptation:

What can be done?





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Key Vulnerability Identified by IPCC

- Decentralized system where adaptation tends to be reactive, unevenly distributed, and focused on coping with, not preventing problems

- Including **climate change considerations into decision making** is key for sustainability

- EPA starting on this track with OW Climate Change Strategy

Adaptation

- Adaptation has several meanings
  - Biological adaptation
  - Adaptive management
  - Strategic responses of managers (may include no response)

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Reducing Impacts to Aquatic Ecosystems

Increase resilience of ecosystems

- Reduce impacts from other stressors (*e.g.*, pollution, acidification, desertification, eutrophication, invasive species)
  - Likely to enhance resilience to climate change
- Maintain habitat connectivity, population sizes, genetic diversity
- Restore habitat
  - Activities need to account for new environmental conditions

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Some specific actions

- Accept moving target paradigm versus steady state model
- Establish sentinel sites for trend monitoring
- Mine historical data records to establish a basis for evaluating climate change
- Improve hydrological and temperature data collection
- Integrate the concept of climate change into planning
- Restore the natural capacity of rivers to buffer climate-change impacts

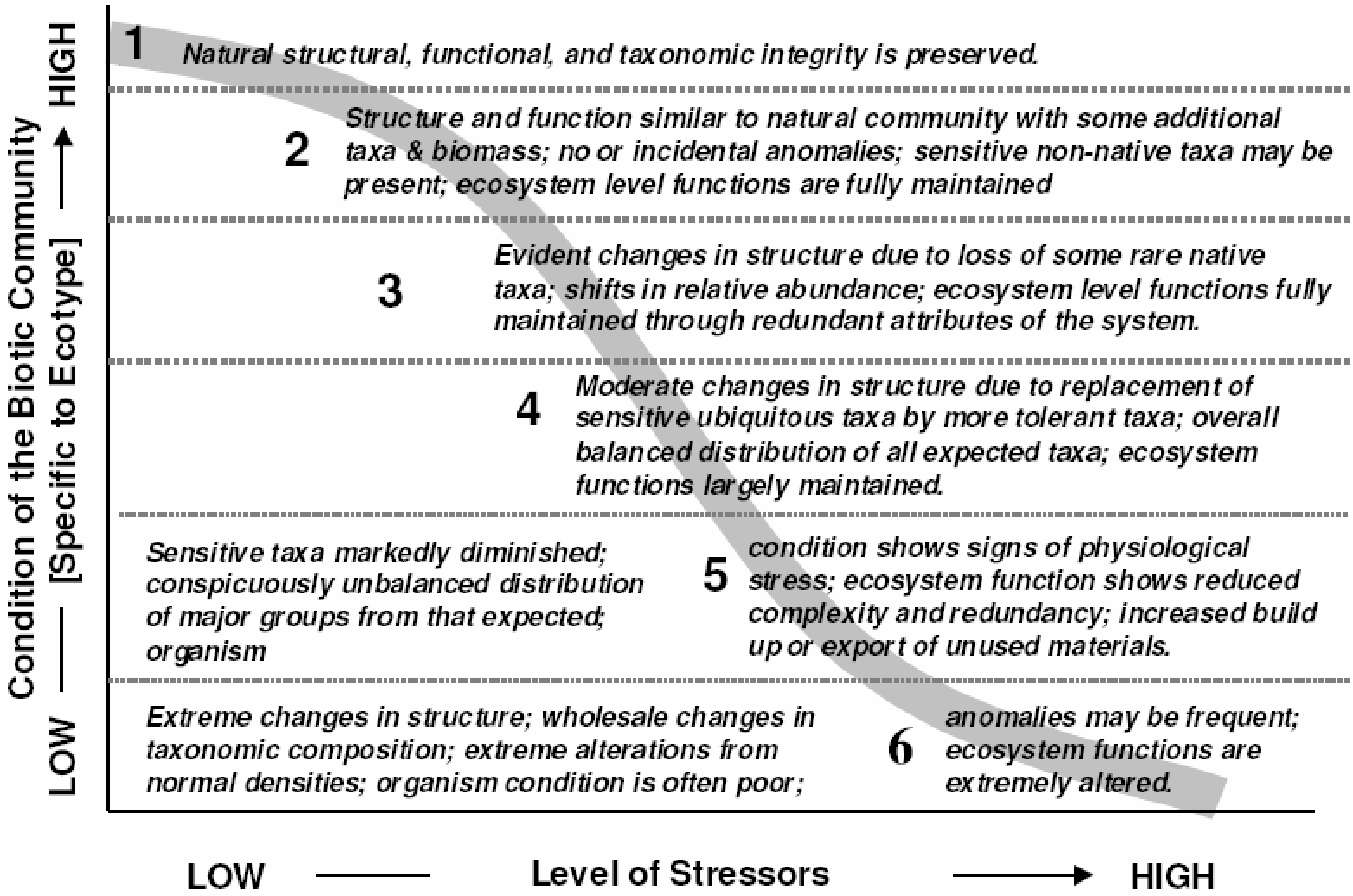

FIGURE 1-1. Conceptual model of the Biological Condition Gradient.

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What's needed for more information?

- Monitoring of reference sites
  - Repeated sampling at same sites
- Baseline data
  - Biotic and abiotic variables (temperature, flow)
  - Species trait information and sensitivities
- Continuous and real time data acquisition
- Linkage between real-time data and near real-time modeling
- Improved year-round infrastructure

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Questions?

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