# Using long-term research and monitoring to measure ecosystem services and their sensitivity to multiple drivers of change

**Colin Beier & Jesse Caputo**
SUNY College of Environmental Science and Forestry

**Collaborating institutions:**

US Geological Survey

Cary Institute of Ecosystem Studies

Syracuse University

Gund Institute of Ecological Economics

Hubbard Brook Research Foundation

Great Lakes Forestry Centre, Natural Resources Canada

**Healthy Forests, Healthy Watersheds**
**Vermont Monitoring Cooperative 2016 Conference**

ESF State University of New York College of Environmental Science and Forestry
Syracuse University — Suos Cultores Scientia Coronat — Founded AD 1870
E&S Environmental Chemistry, Inc.
USGS science for a changing world
Adirondack Lakes Survey Corporation www.adirondacklakessurvey.org
New York State of Opportunity. | NYSERDA Supported
NSRC Northeastern States Research Cooperative

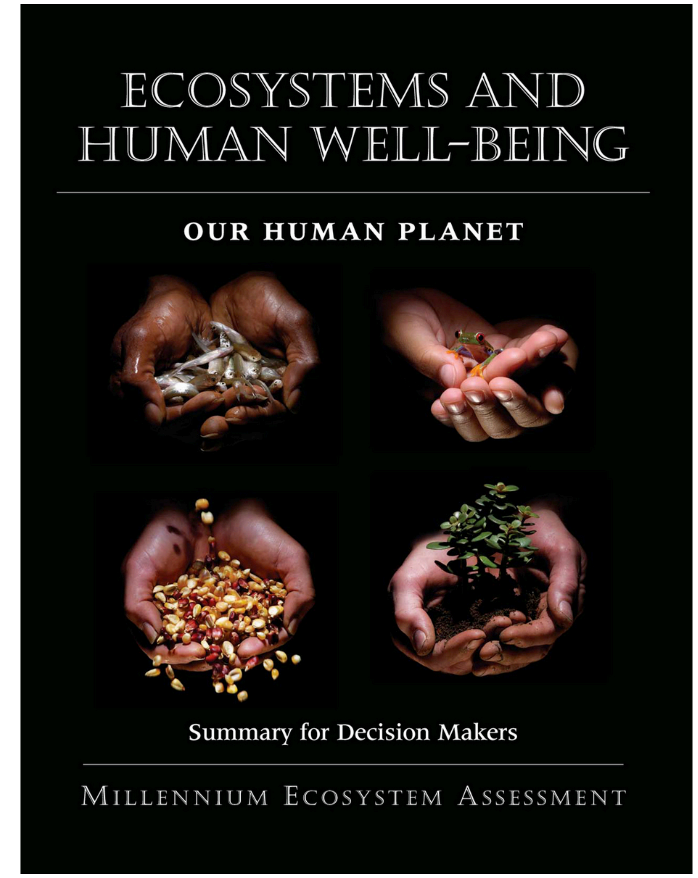
# Why measure ecosystem services?

Better accounting of cost-benefit and externalities of environmental management and decision-making

Identify beneficiaries of stewardship and conservation efforts

Provides evidence to policy-makers and public that the human condition is coupled with environmental condition

Can provide monetary and non-monetary estimates of value



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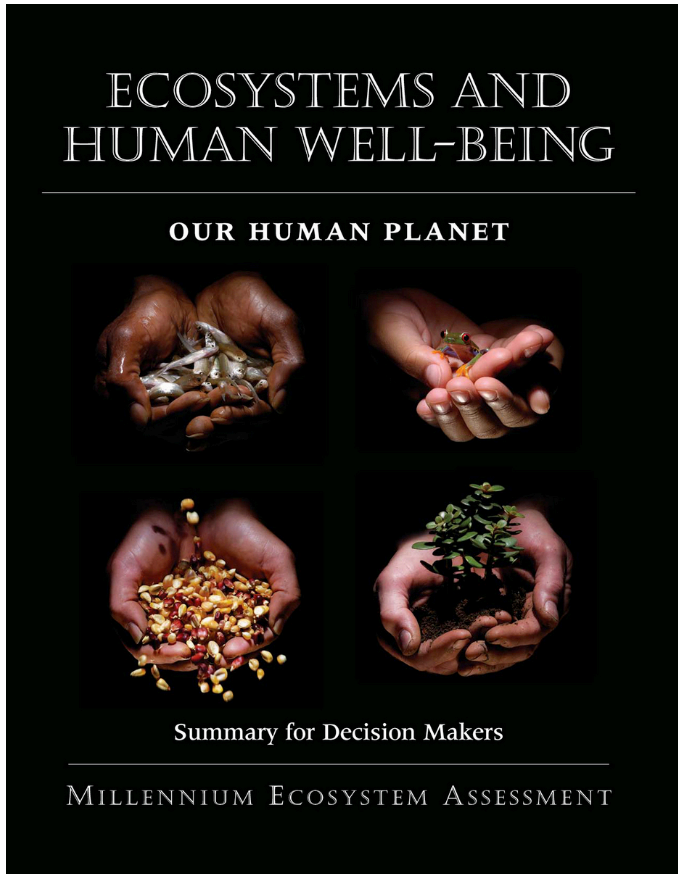



# Why use long-term research and monitoring?

Captures dynamics over time, responses to multiple drivers of change

Monitoring of long-term experiments and reference conditions provide basis for causal inference, prediction, and simulation

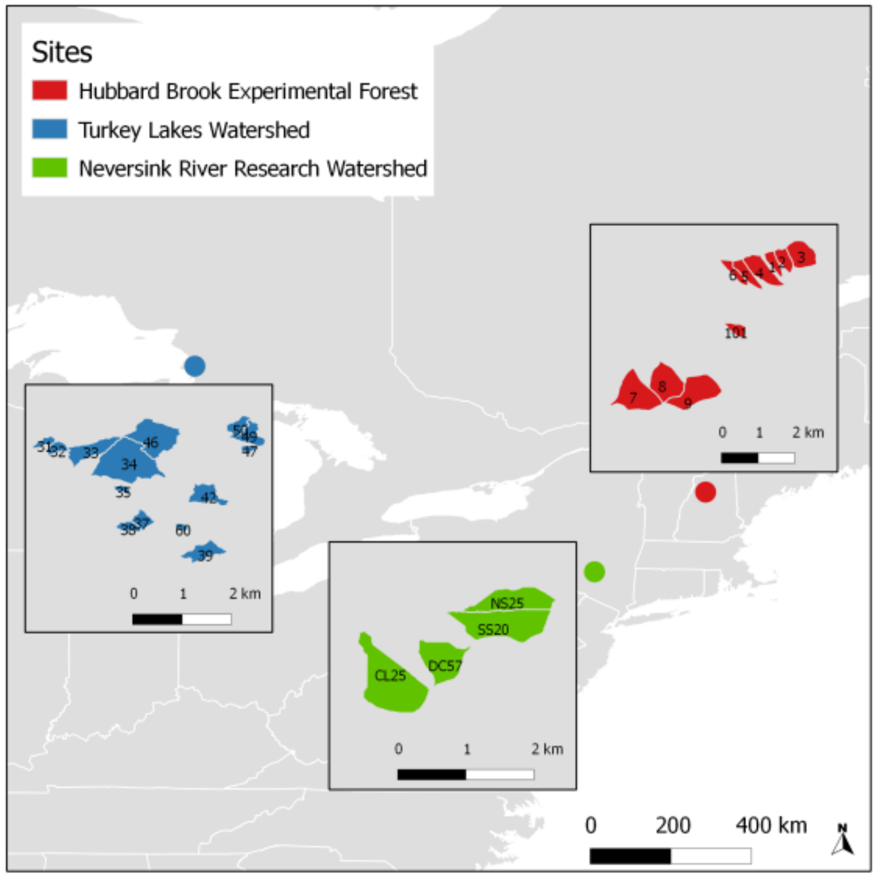
Funding agencies shifting to long-term **social**-**ecological** research

Demonstrate the many value-added aspects of monitoring efforts

# FEST measures whether ecosystem conditions and dynamics 'match' human demand for different types of benefits

# Forest Ecosystem Services Toolkit: Purpose & Approach

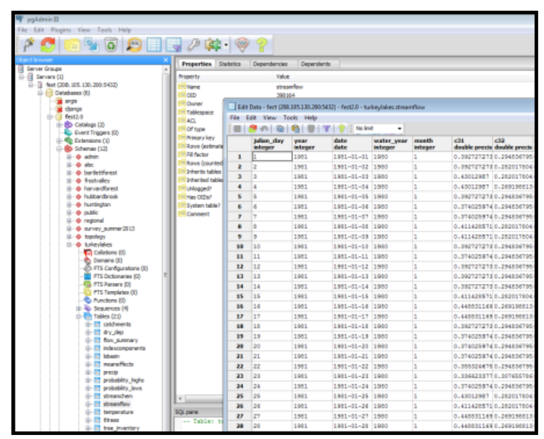
## FEST measures whether ecosystem conditions and dynamics ‘match’ human demand for different types of benefits

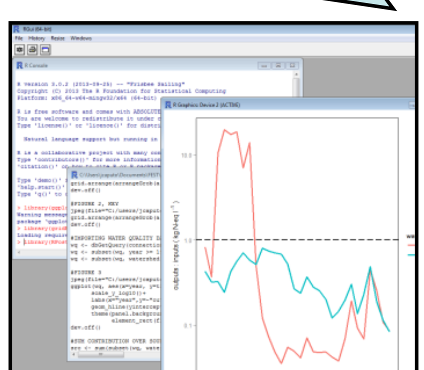



**Long-term experimental research sites**
Ecosystem studies
Watershed approach
Forest harvest treatments
  Forest removal
  Harvest techniques
  Silvicultural prescriptions

**Open source geodatabase & modeling platform**
PostgreSQL and Program R
159 individual datasets
Interactive data visualization

FEST Knowledge Base (PostgreSQL)





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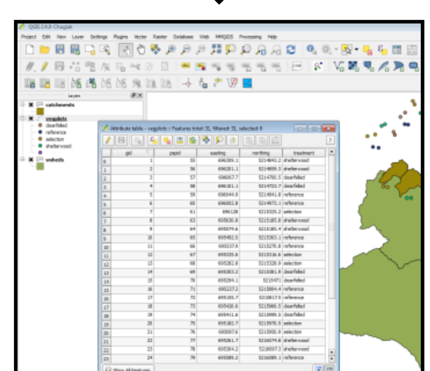
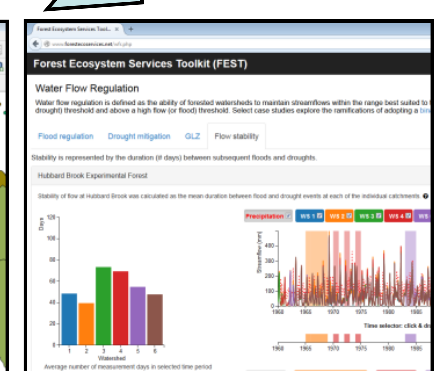
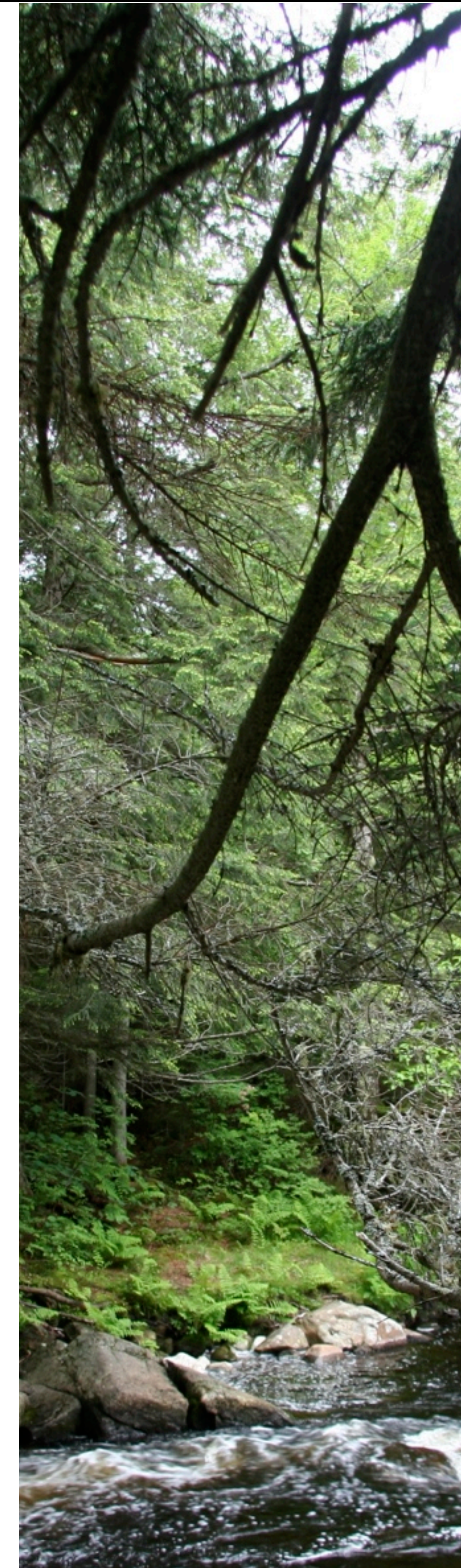


QuantumGIS




FEST Website



Using ‘big data’ from long-term monitoring and experiments to measure ecosystem services

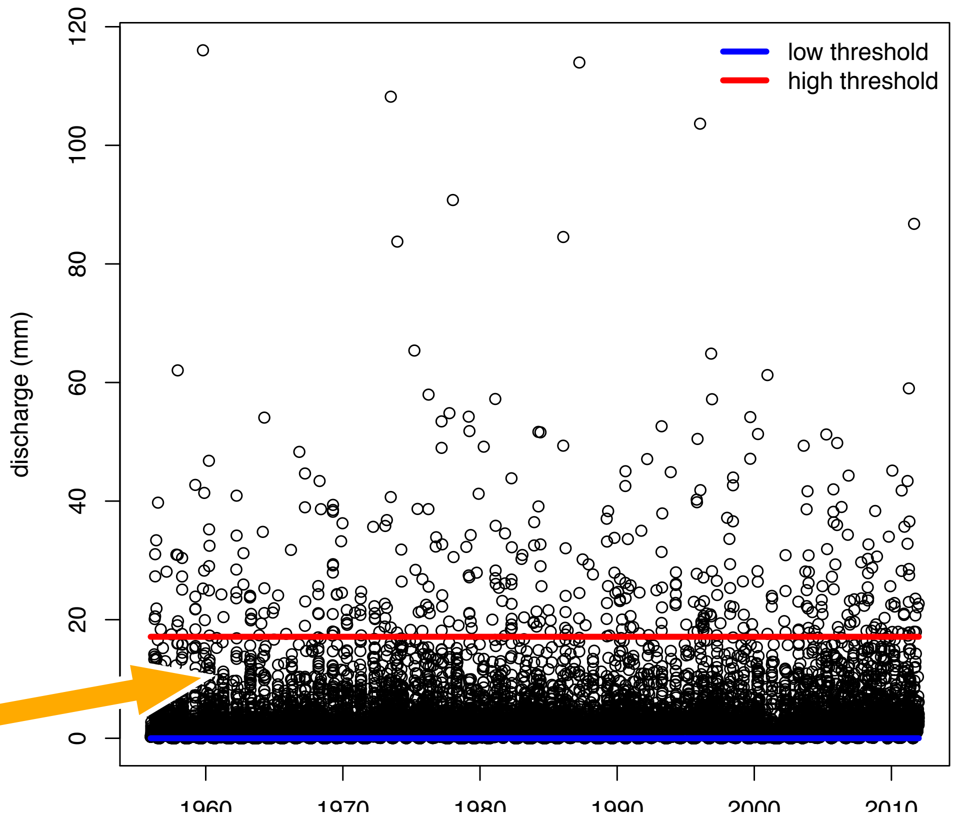
## Flow regulation

We compared precipitation and stream discharge data with historical water use and the engineering specs of the Franklin Falls Dam.

Assessed discharge data (rescaled) using two demand thresholds:

- level required to satisfy Grafton Co, NH water usage
- level exceeding the maximum outflow of the dam

Metrics included flood prevention, drought mitigation and stability.




*"the Goldilocks Zone"*

▲ Daily stream discharge at Hubbard Brook WS2 (1955-2011) and high/low thresholds.

# Methods: water regulation at Hubbard Brook

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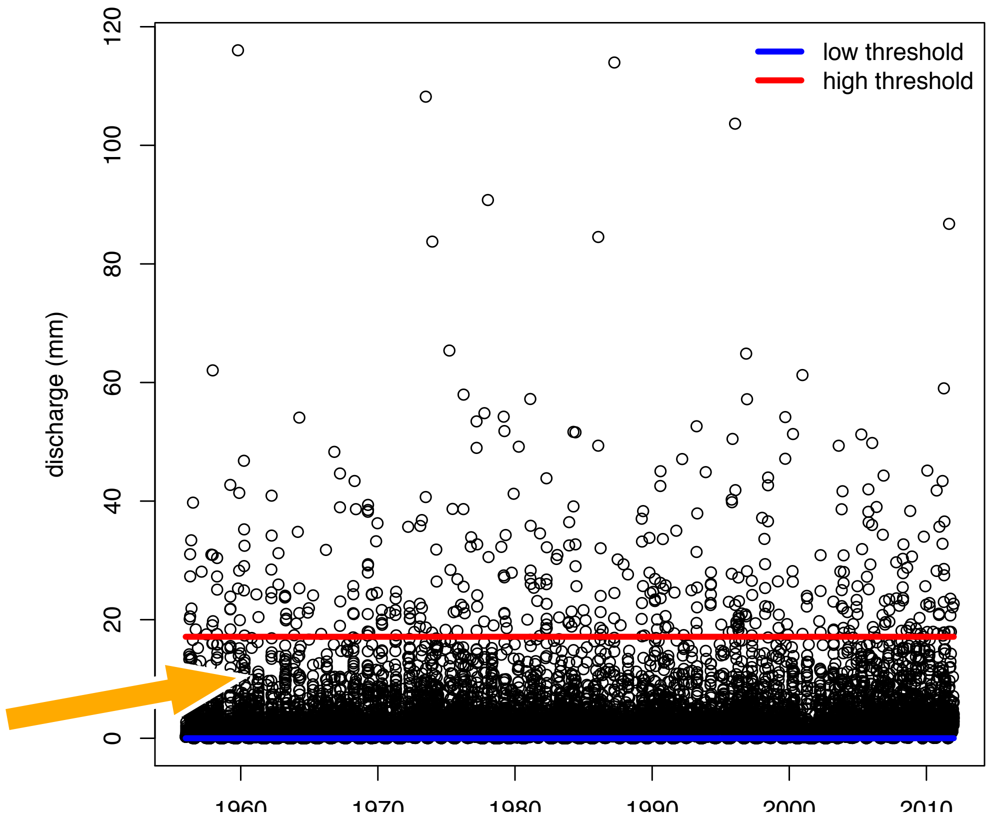


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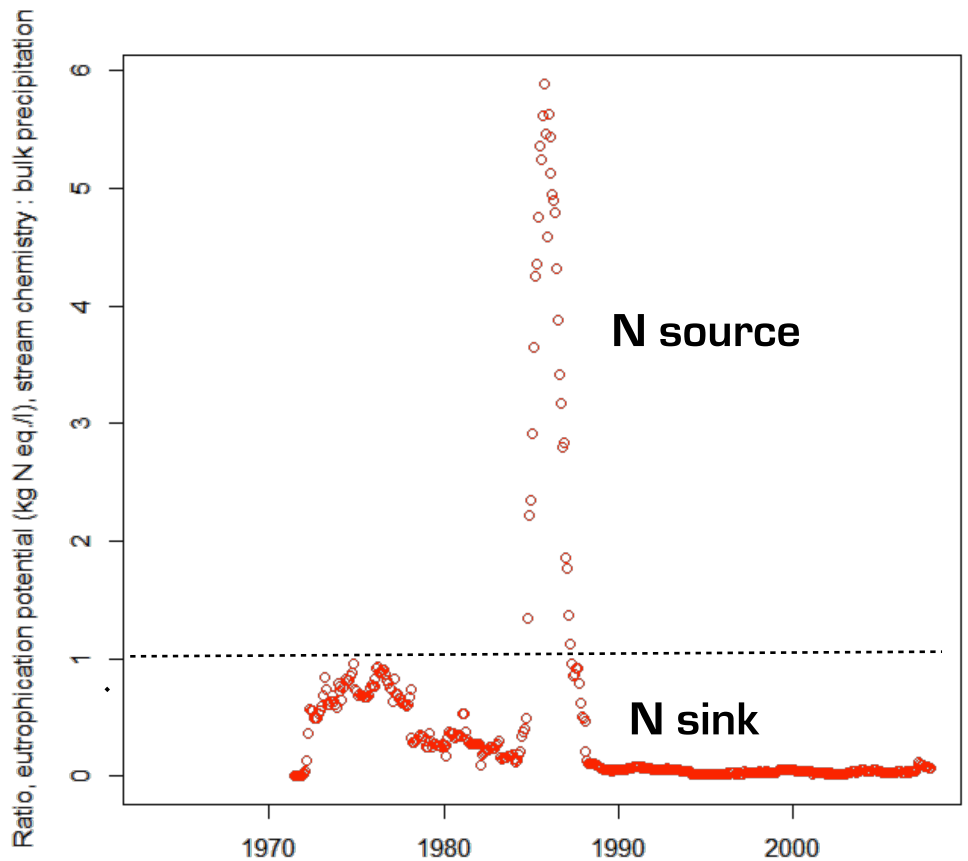


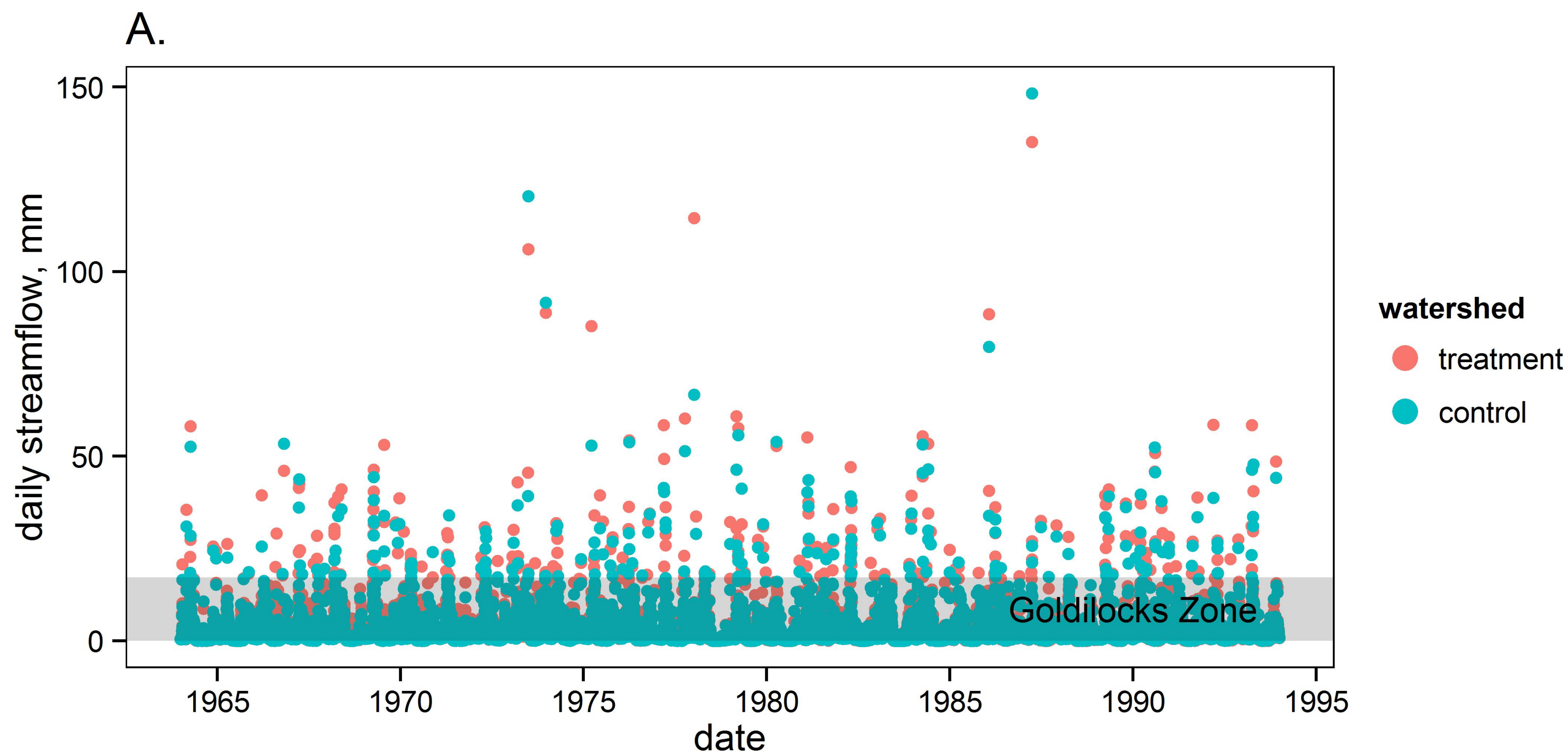

◀ Ratio of eutrophication potential (kg N eq/l) of stream water to that of precipitation, in WS5 at Hubbard Brook. Values < 1 indicate capacity to remove pollution.

## Quality regulation

We compared stream chemistry data with state and federal water quality standards as measures of societal demand.

Relationships between functional loads (bulk deposition) and stream chemistry were used to quantify watershed capacity to reduce eutrophication potential of precipitation inputs.

# Water flow regulation: forest removal and recovery at Hubbard Brook

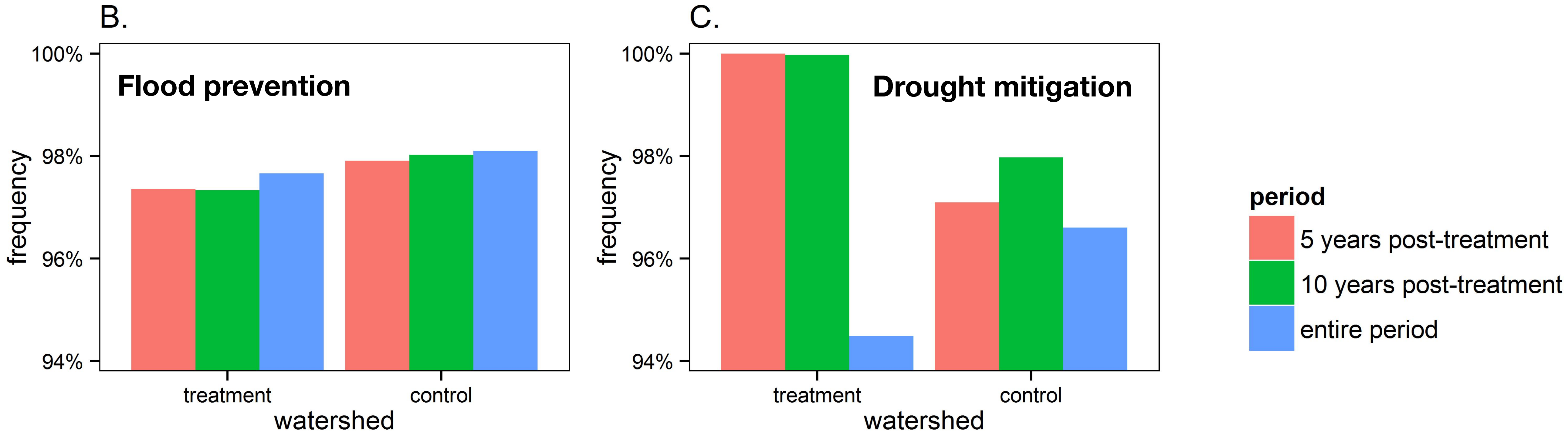



Flow regulation provided by both watersheds

Flood prevention slightly lower in deforested WS

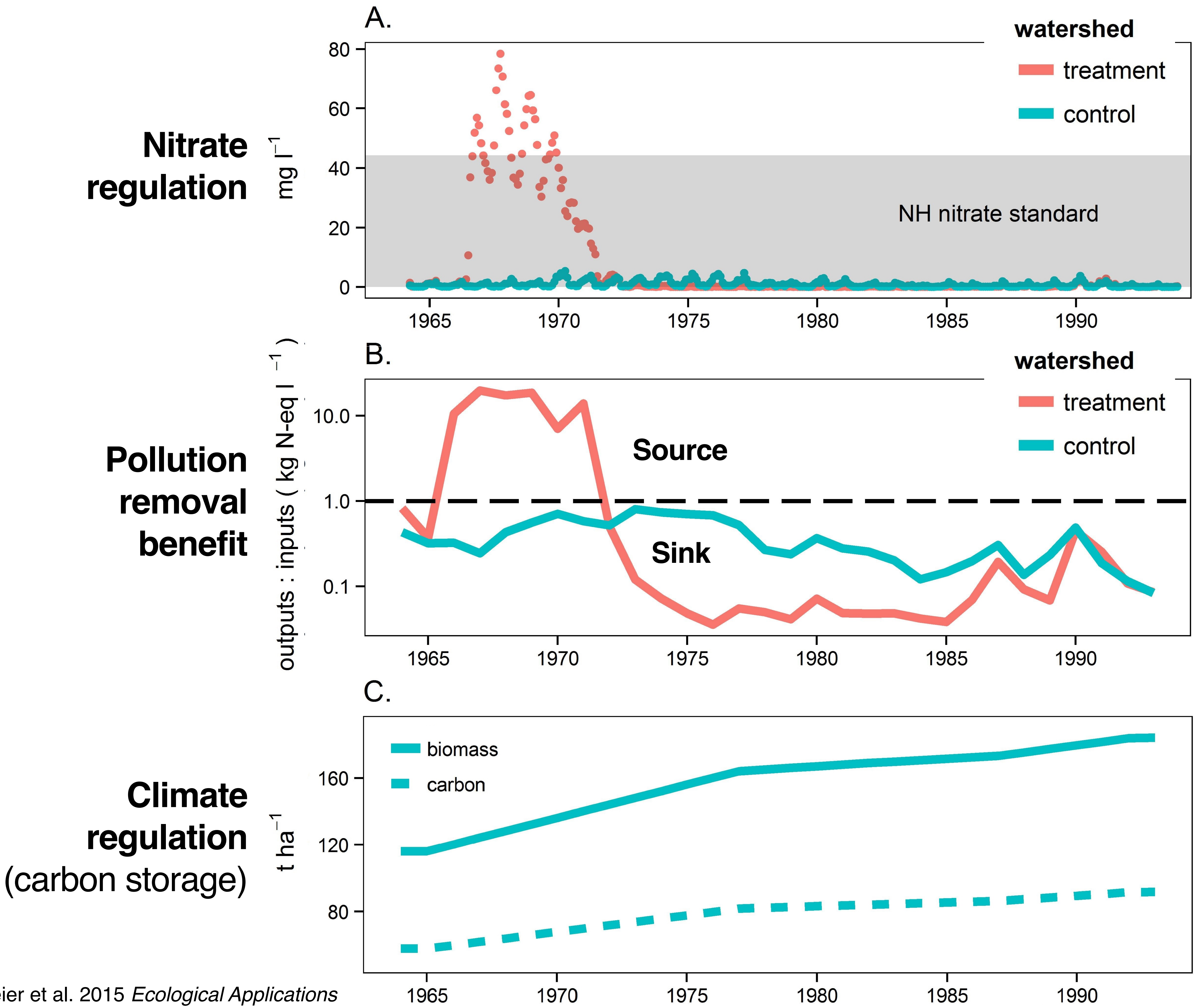
Drought mitigation higher in deforested WD during and after treatment

**experiment was done during 1960’s drought**




Beier et al. 2015 *Ecological Applications*

# Water quality and climate regulation: deforestation and recovery at Hubbard Brook




Beier et al. 2015 *Ecological Applications*

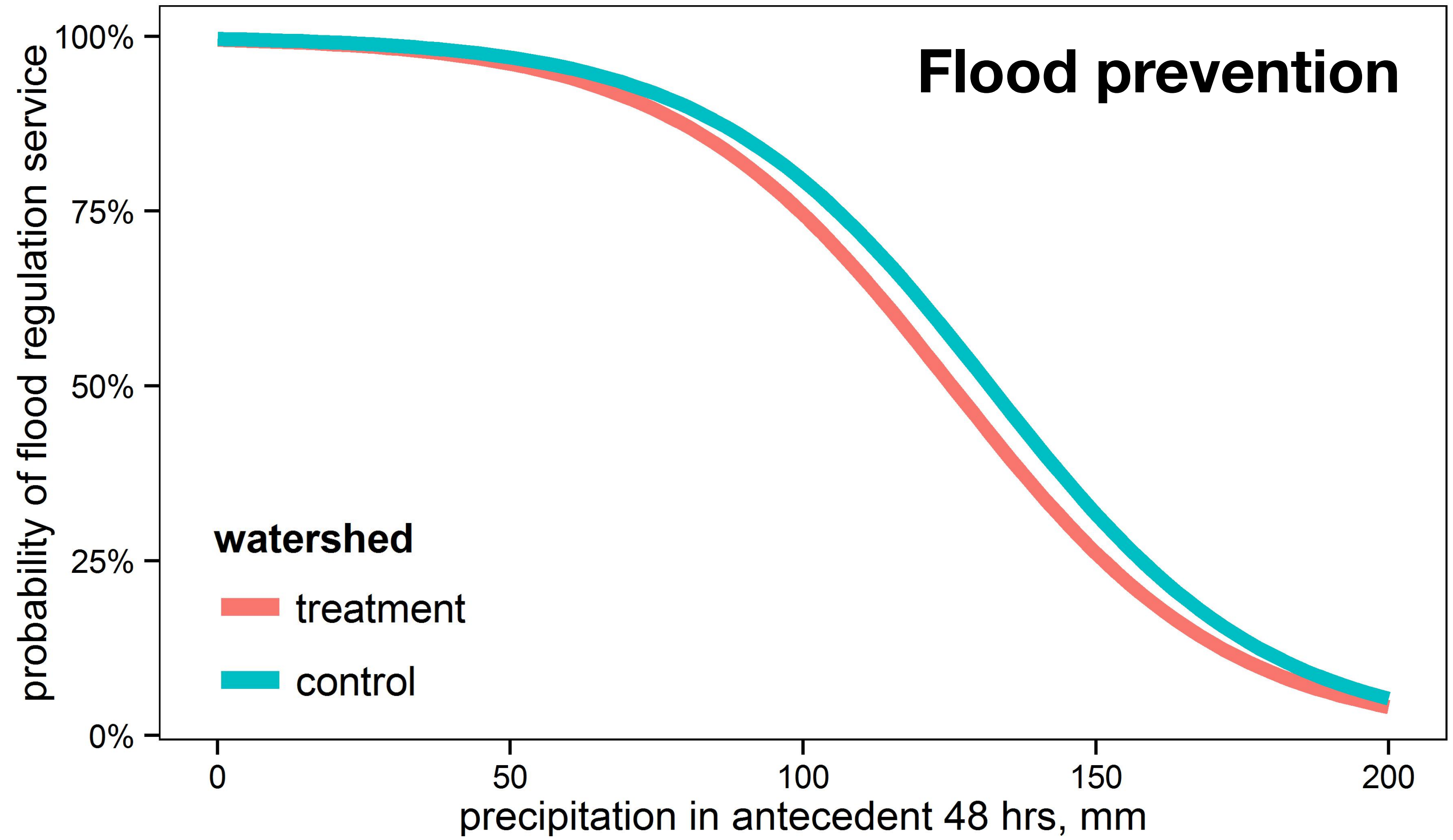
How can we account for interacting drivers of change and varying functional loads on ecosystems?

# Flow regulation in a deforested watershed: changing functional loads

Logistic model based on 10 years after WS 2 de-vegetation

Deforested watershed reached flood stage with 0-10 mm less rainfall than unharvested reference (depending on storm intensity)

Does not reflect magnitude of floods - only occurrence

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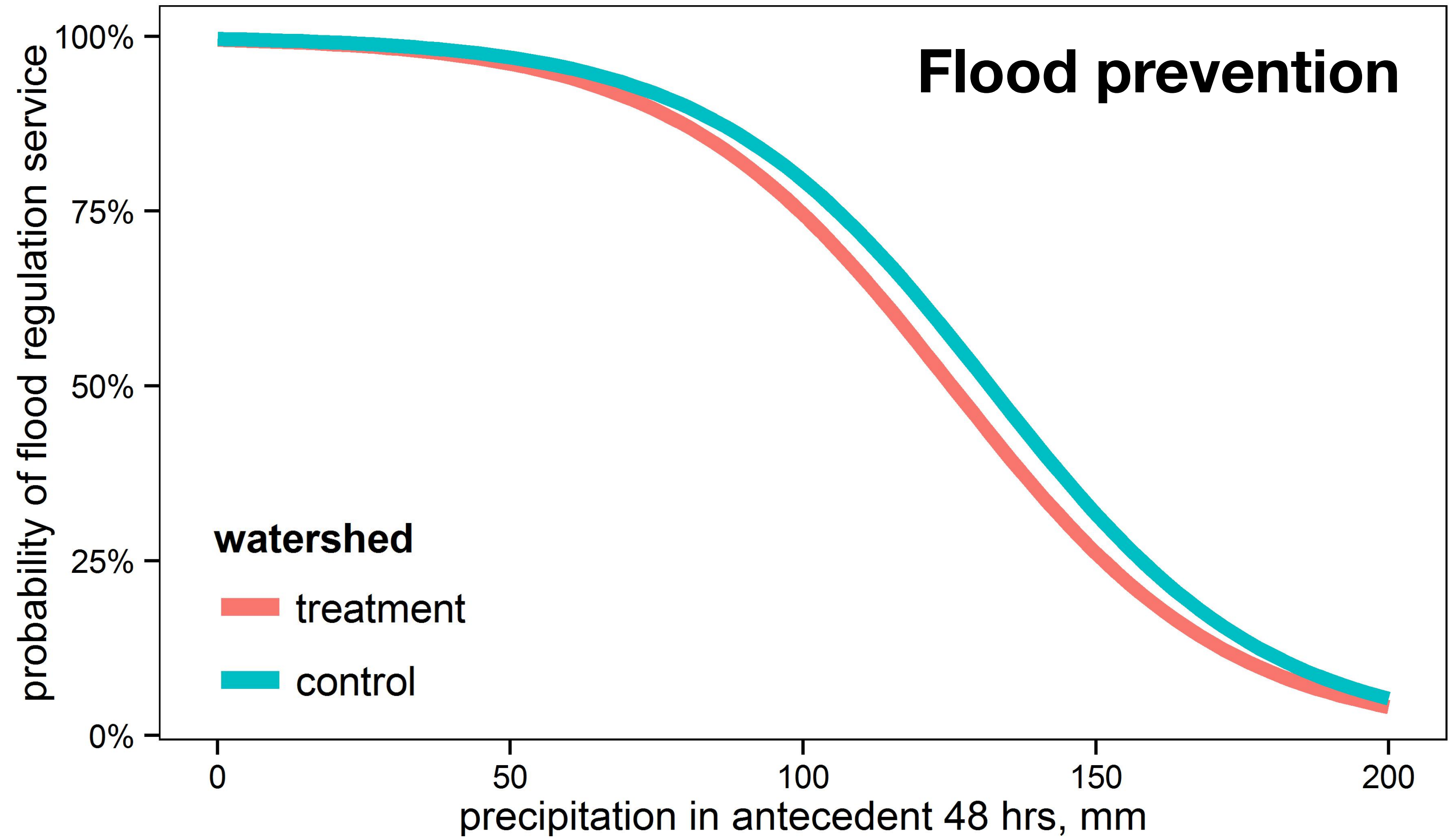
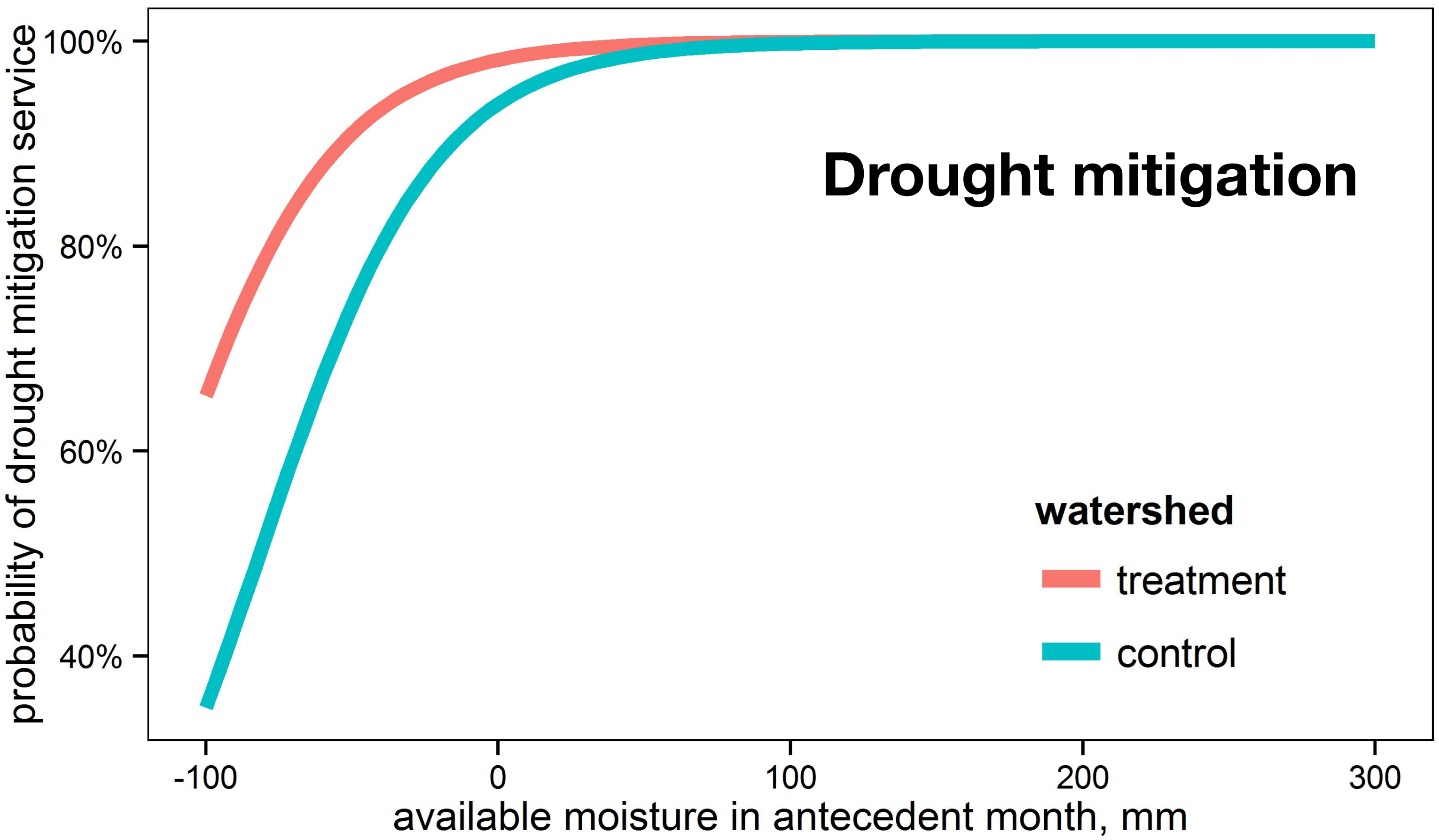


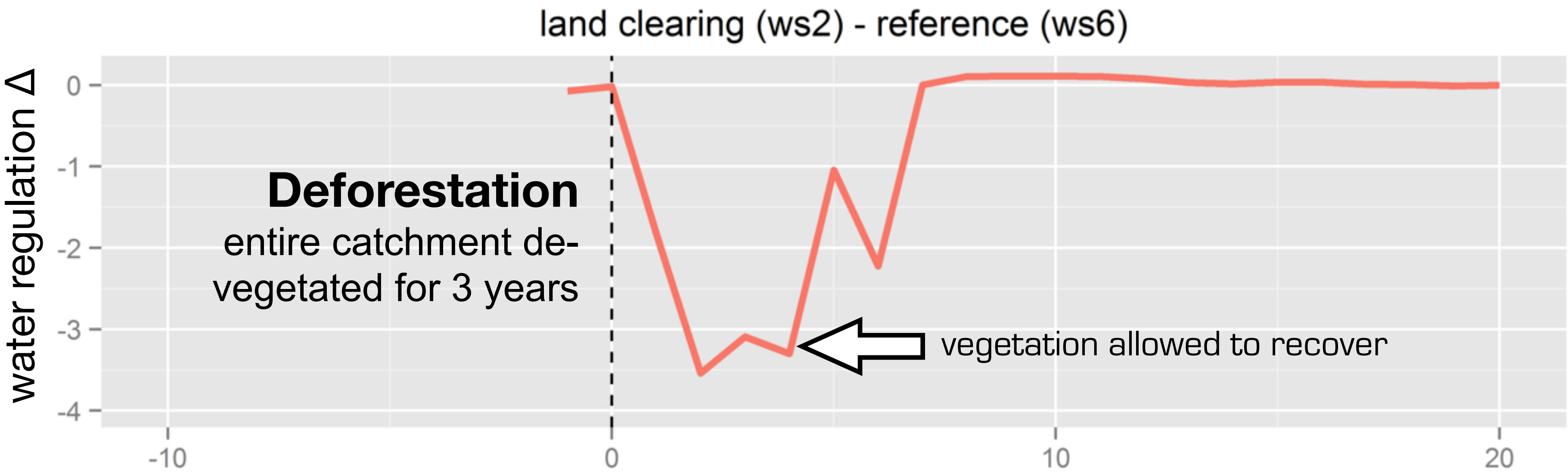

Logistic model based on 10 years after WS 2 de-vegetation

Deforested watershed was 25% more likely to maintain base flows during a severe deficit (drought) (b/t -50 to -100 mm available moisture)

Beier et al. 2015 *Ecological Applications*

How well do managed forests regulate water?

# Deforestation vs. management: integrated impacts on water regulation benefits



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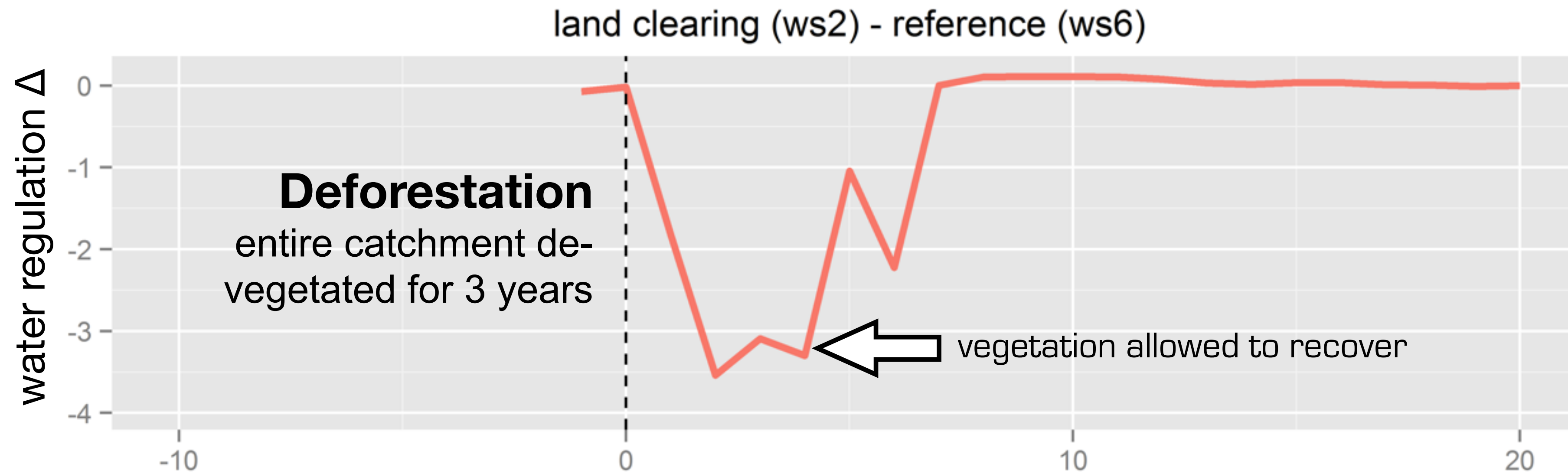


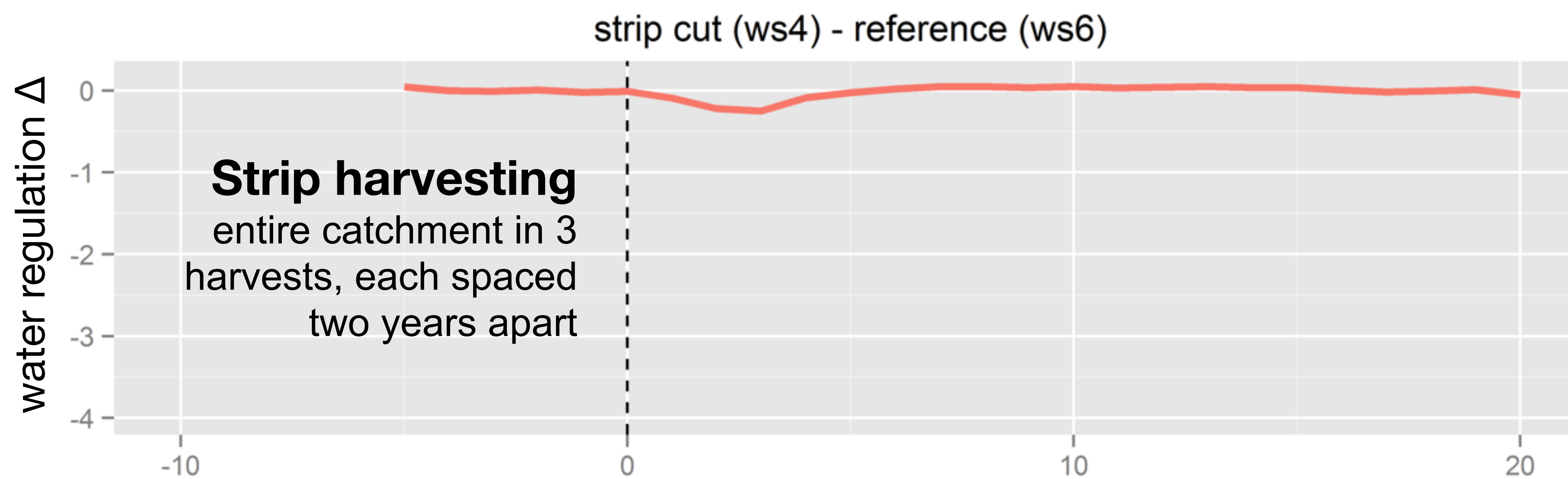

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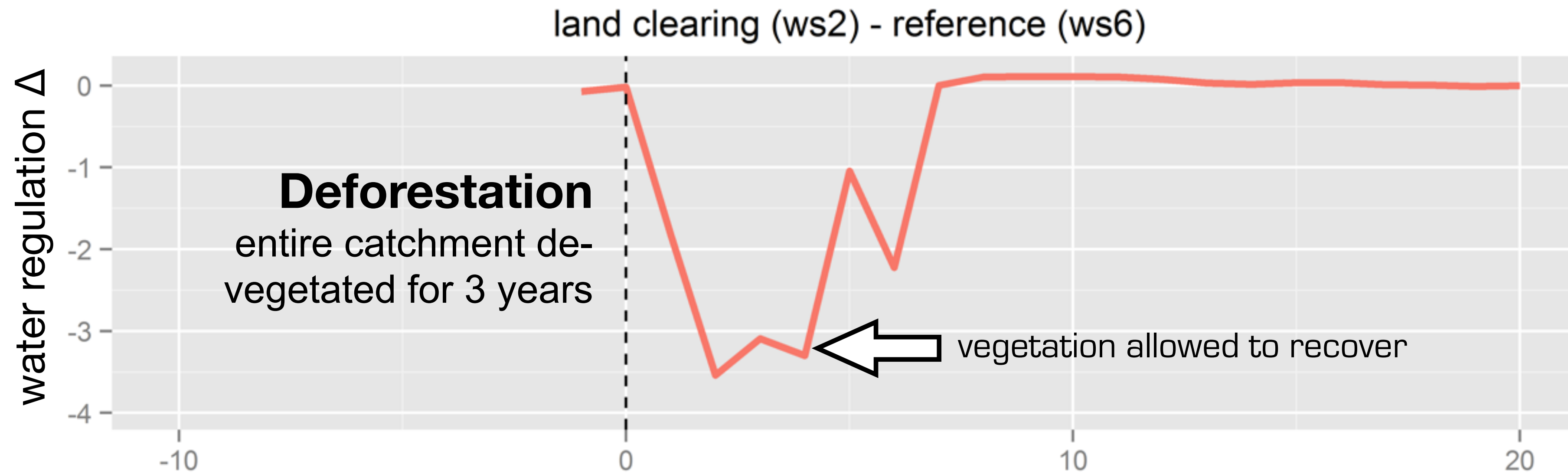
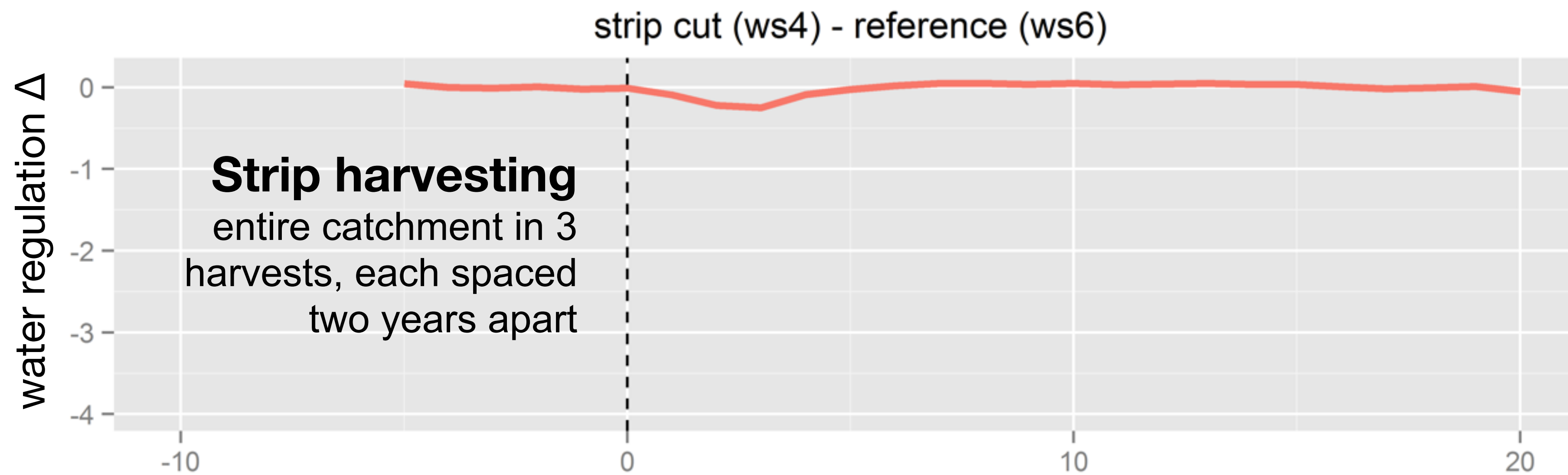
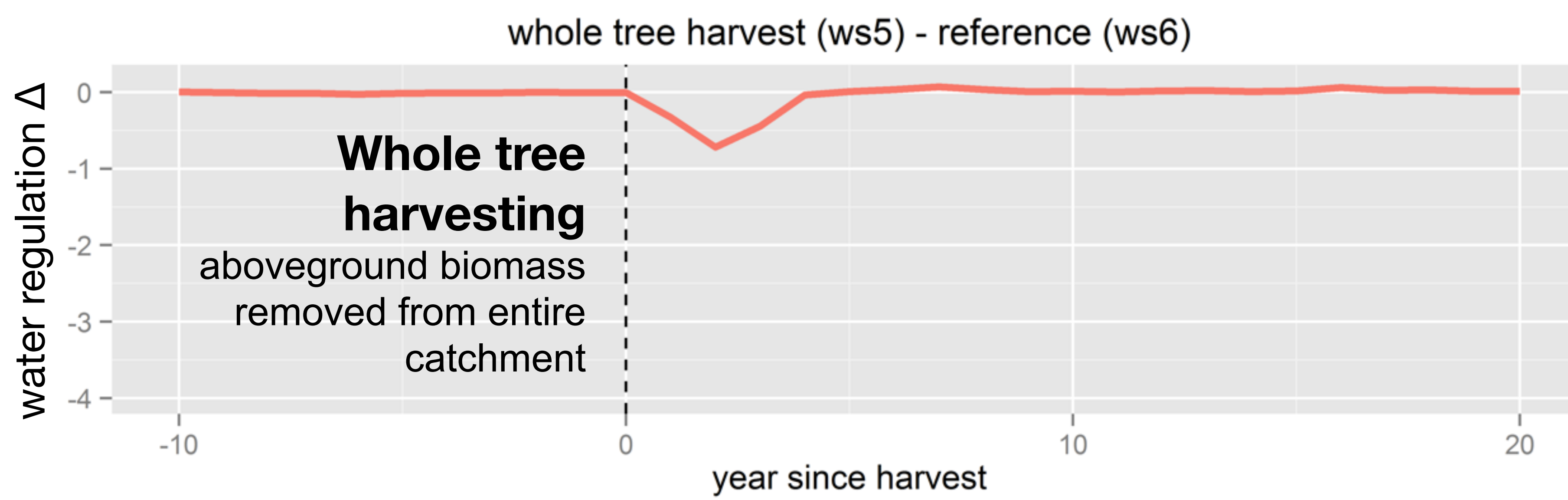
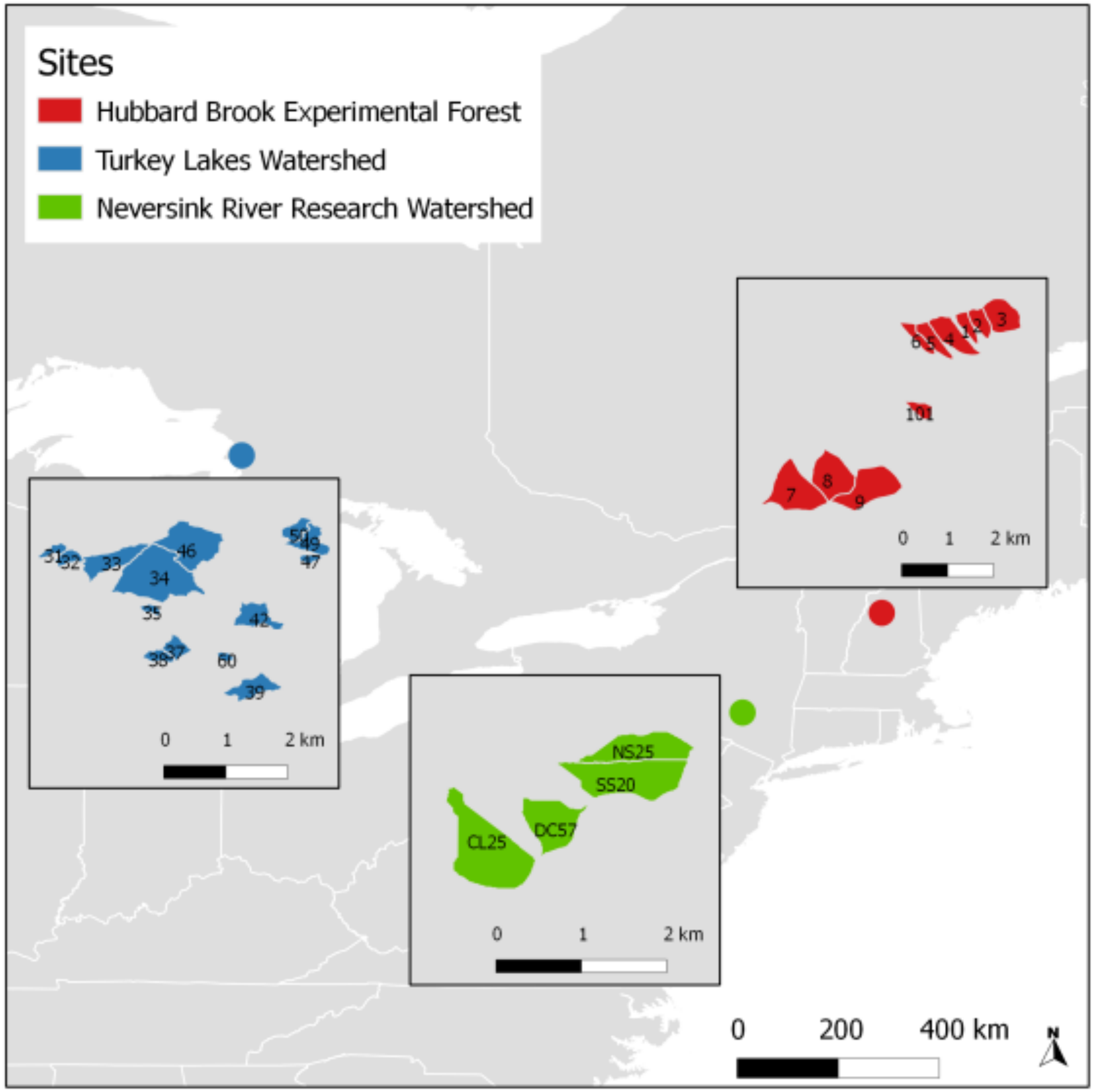


# 10 watersheds, 10 management prescriptions, 10 services...



# 10 watersheds, 10 management prescriptions, 10 services...

**Table 1.** Study Watersheds at Three Sites in Northeastern North America, Hubbard Brook Experimental Forest (HB), Turkey Lakes Watershed (TL), and Neversink River Research Watershed (NR)

| Watershed | Site | Original (local) name | Description |
|---|---|---|---|
| HB-R | HB | 6 | Reference |
| HB-H1 | HB | 4 | Strip clearcut; harvested in sequential 25-m strips in 1970, 1972, and 1974; streamside buffers left unharvested |
| HB-H2 | HB | 5 | Clearcut; whole-tree harvest in late 1983; all residues removed |
| NR-R | NR | CL25 | Reference |
| NR-L | NR | SC40 | Timber stand improvement cutting; 5.6% of the basal area on approximately 32% of the watershed area was removed in 1995–1996 |
| NR-H | NR | DC57 | Partial clearcut; 97% of the basal area was removed in 75% of the watershed area in 1996–1997 |
| TL-R | TL | 32 | Reference |
| TL-L1 | TL | 33 | Selection harvest; 29% basal area removed in 1997 |
| TL-L2 | TL | 34 | Shelterwood harvest; 42% basal area removed in 1997 |
| TL-H | TL | 31 | Diameter-limit harvest; all trees >10 cm were removed in 1997, equivalent to 89% of the basal area |

*Watersheds are labeled by site and by cutting intensity.*
*H = high intensity; L = low intensity; R = reference.*

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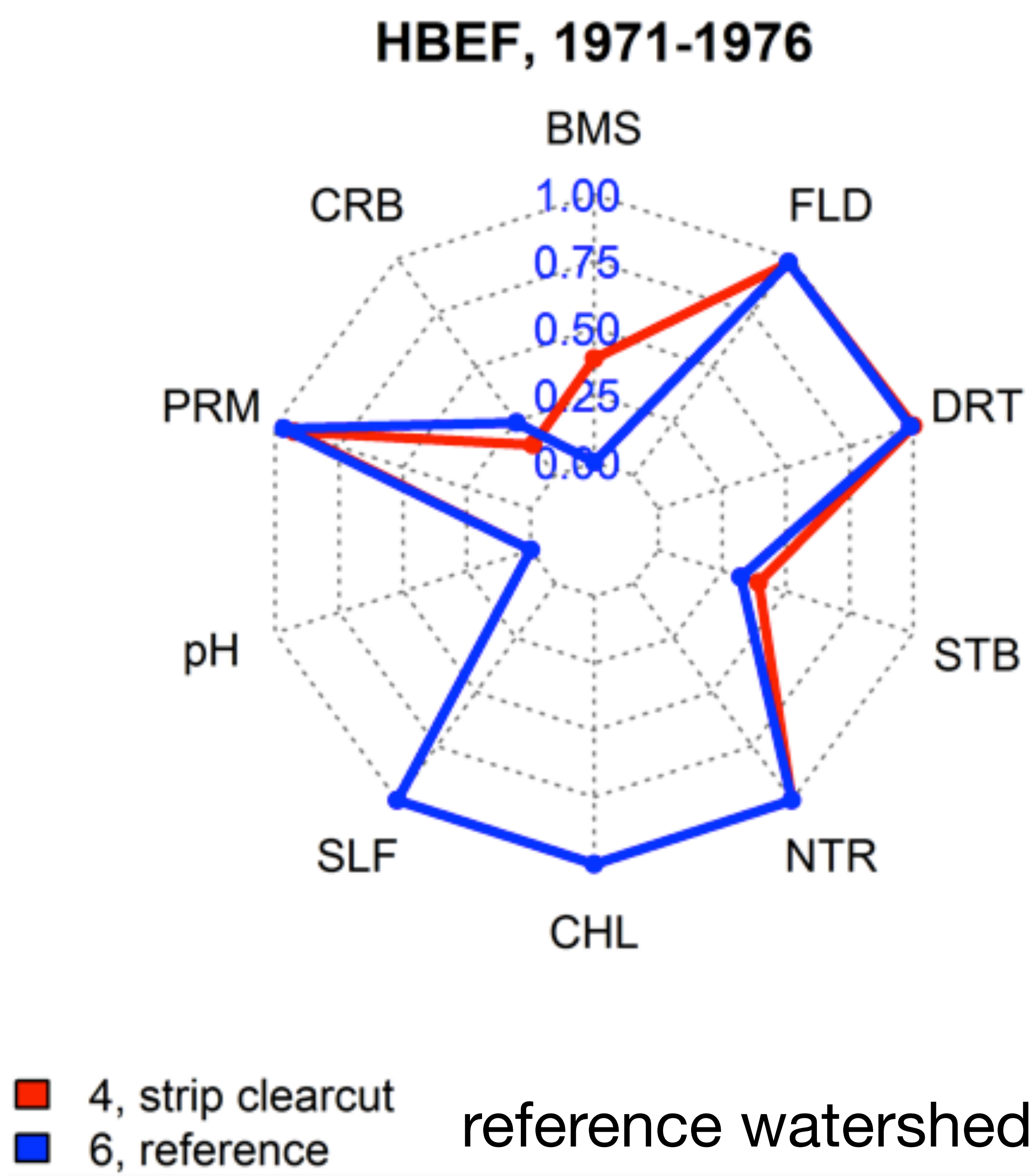


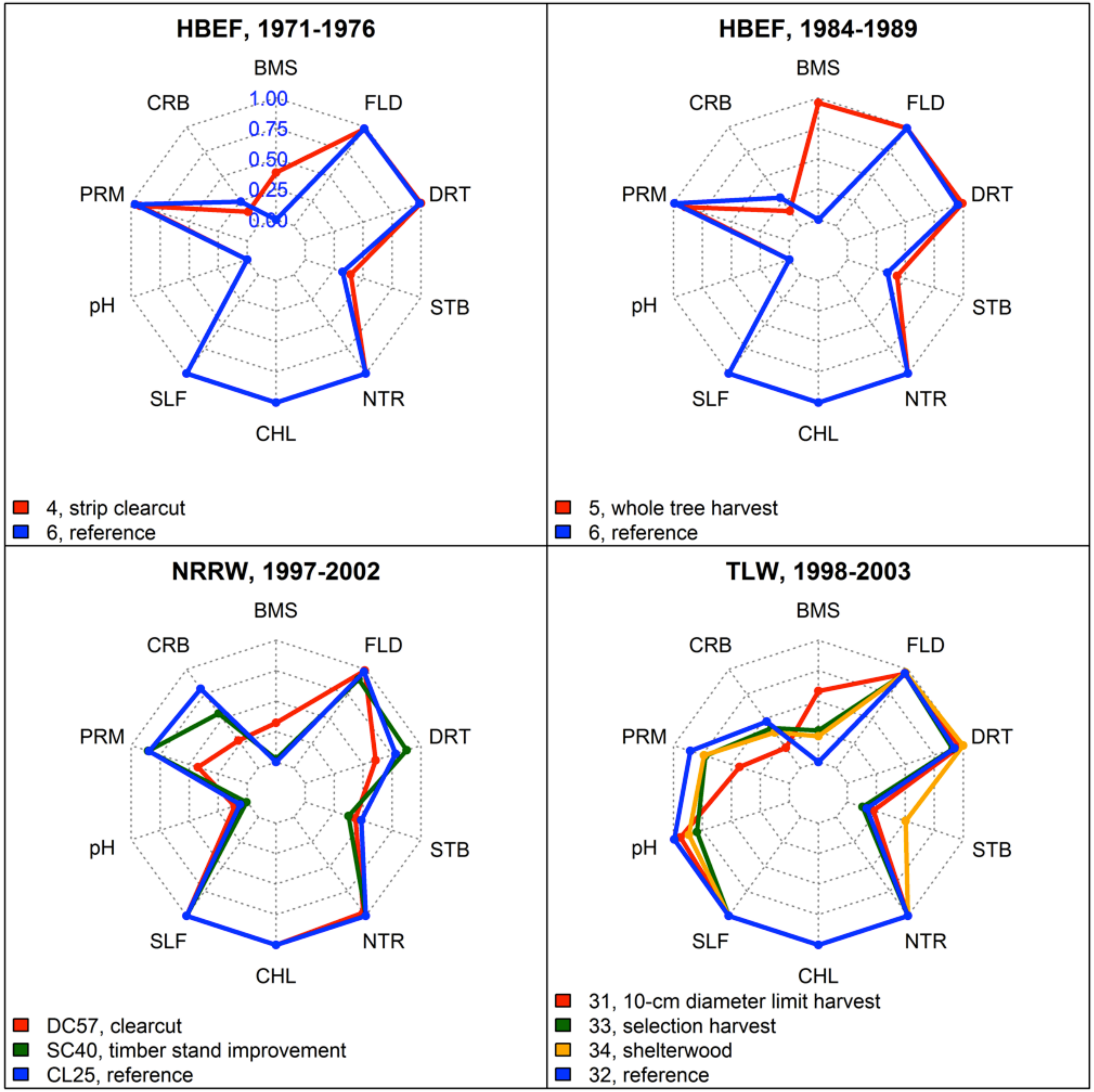

reference watershed is always blue

| | |
|---|---|
| CRB = Climate regulation benefit | BMS = Biomass production |
| PRM = Pollution removal benefit | FLD = Flood prevention |
| pH = pH regulation | DRT = Drought mitigation |
| SLF = Sulfate regulation | STB = Flow stability |
| CHL = Chloride regulation | NTR = Nitrate regulation |

# Forest management impacts: synthesis of multiple watershed experiments

We scaled the 10 ES metrics to allow for comparison across sites and types of benefits

**HBEF: Hubbard Brook, NH**
**NRRW: Frost Valley, NY**
**TLW: Turkey Lakes, ON**

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**HBEF: Hubbard Brook, NH**
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Observed change in 5 year period after harvest:

**(∅) Water regulation**
**(–) Climate regulation**
**(–) Pollution removal**

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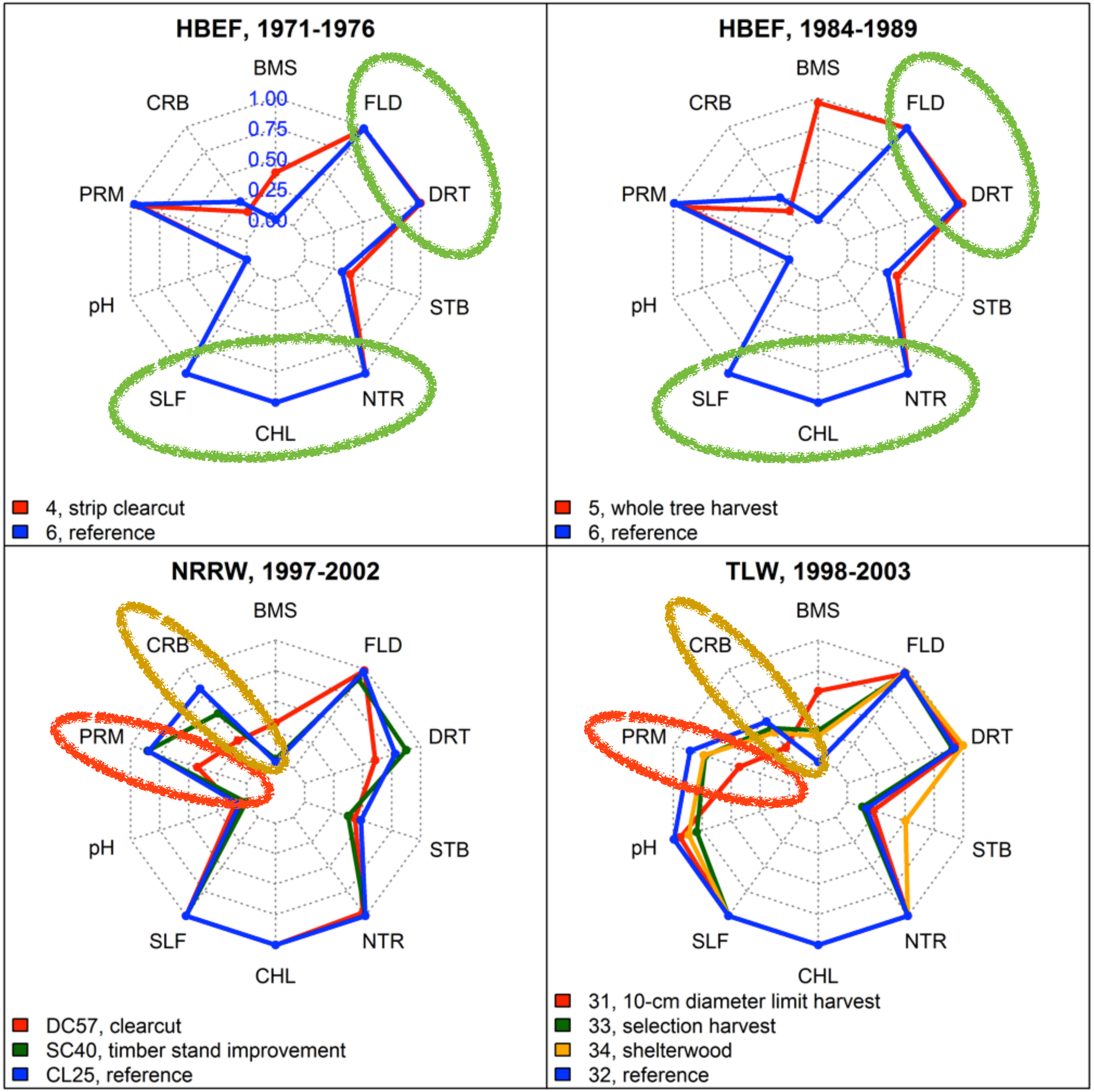

# Forest management impacts: flow regulation under changing functional loads

Probability of flood prevention benefit

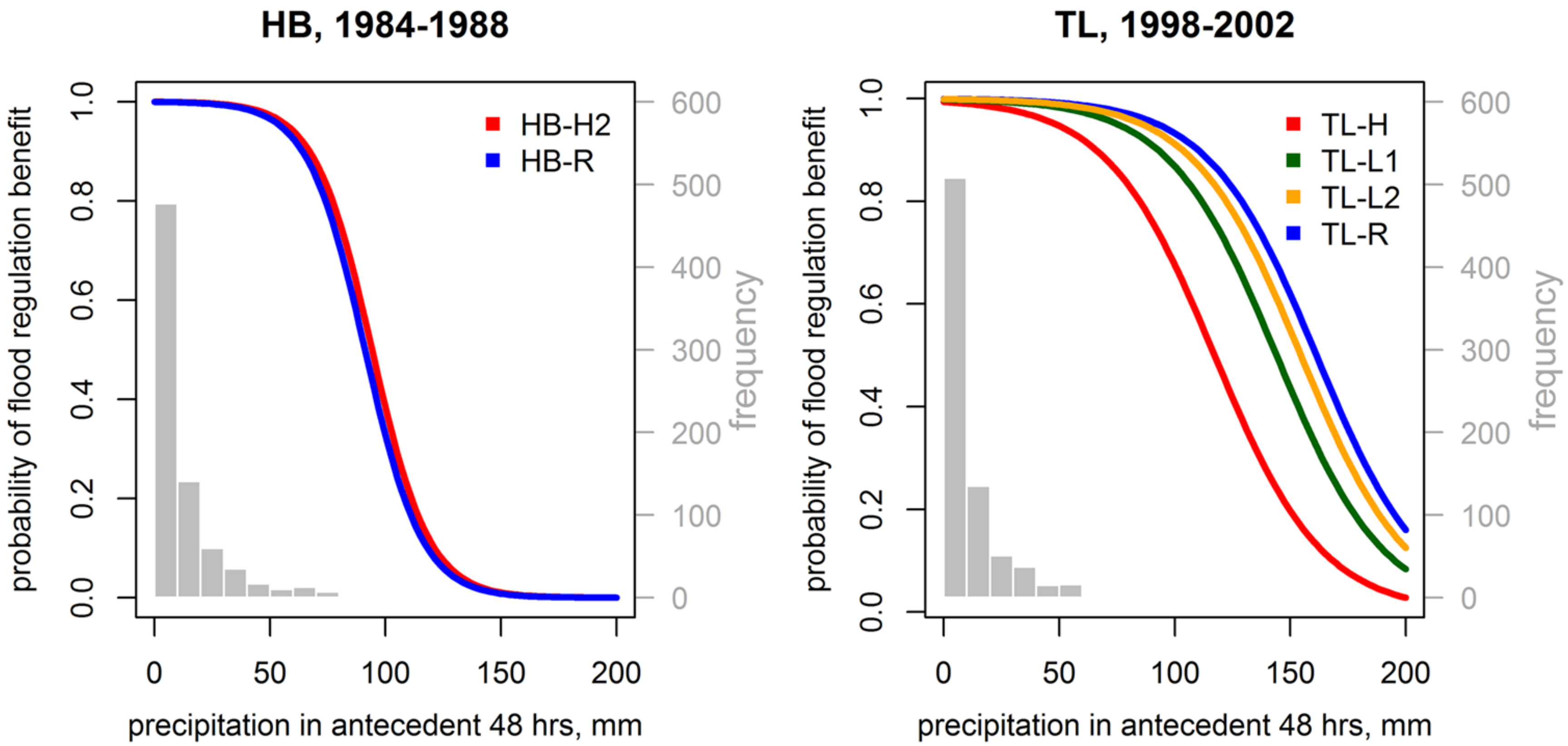


**Figure 2.** Probability of flood prevention and drought mitigation benefits at selected watersheds at Hubbard Brook Experimental Forest (HB) and Turkey Lakes Watershed (TL) over the 5-year period after harvest, modeled as a function of antecedent precipitation (48 h) and available moisture (1 month). Histograms illustrate the distribution of the relevant functional load at the reference watershed. HB-H2 (clearcut with whole-tree harvest) was harvested in 1983. Watersheds TL-H (diameter-limit harvest), TL-L1 (selection harvest), and TL-L2 (shelterwood harvest) were harvested in 1997. Watersheds HB-R and TL-R are unharvested references.

Caputo et al. 2015 Ecosystems

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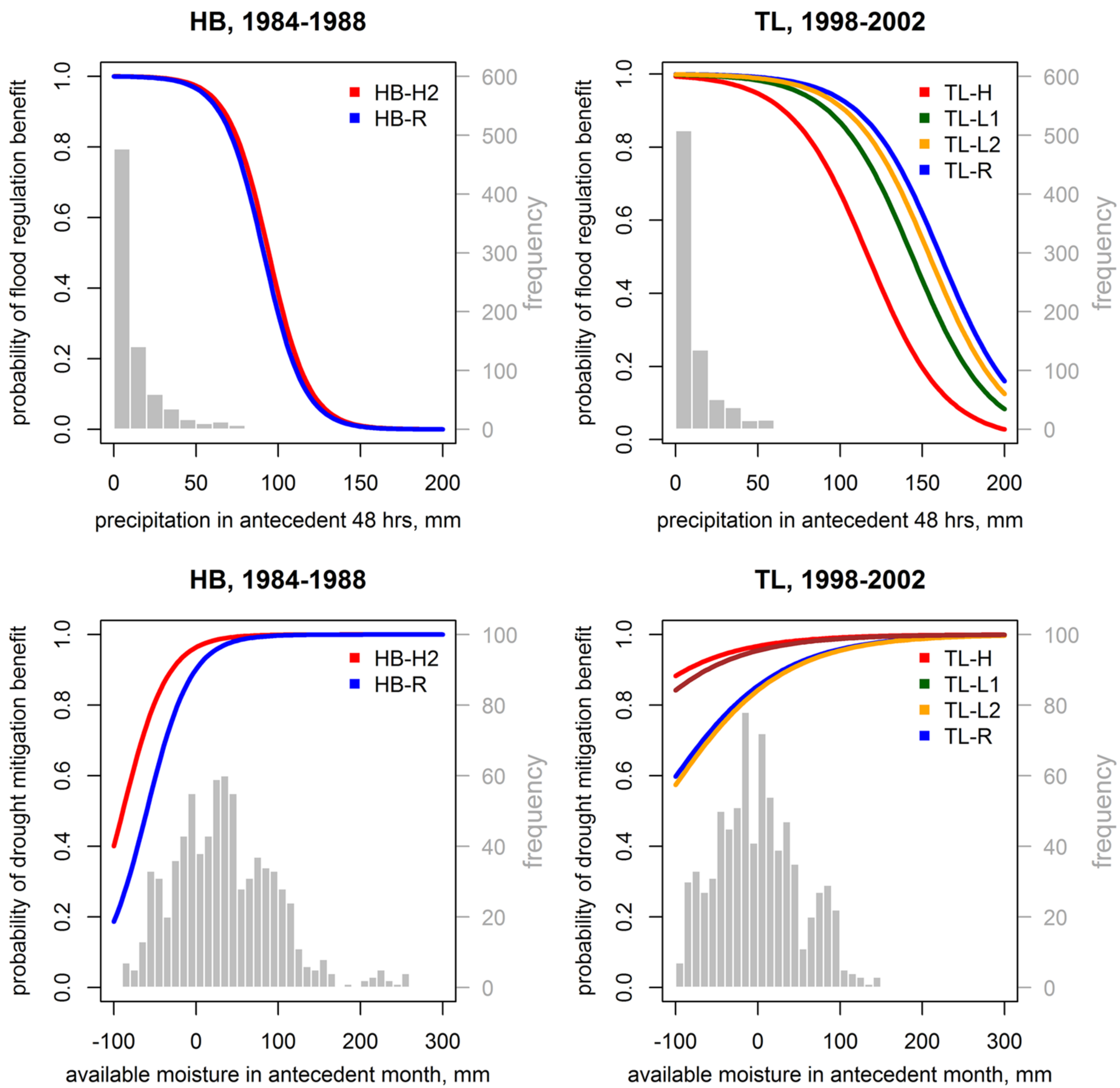


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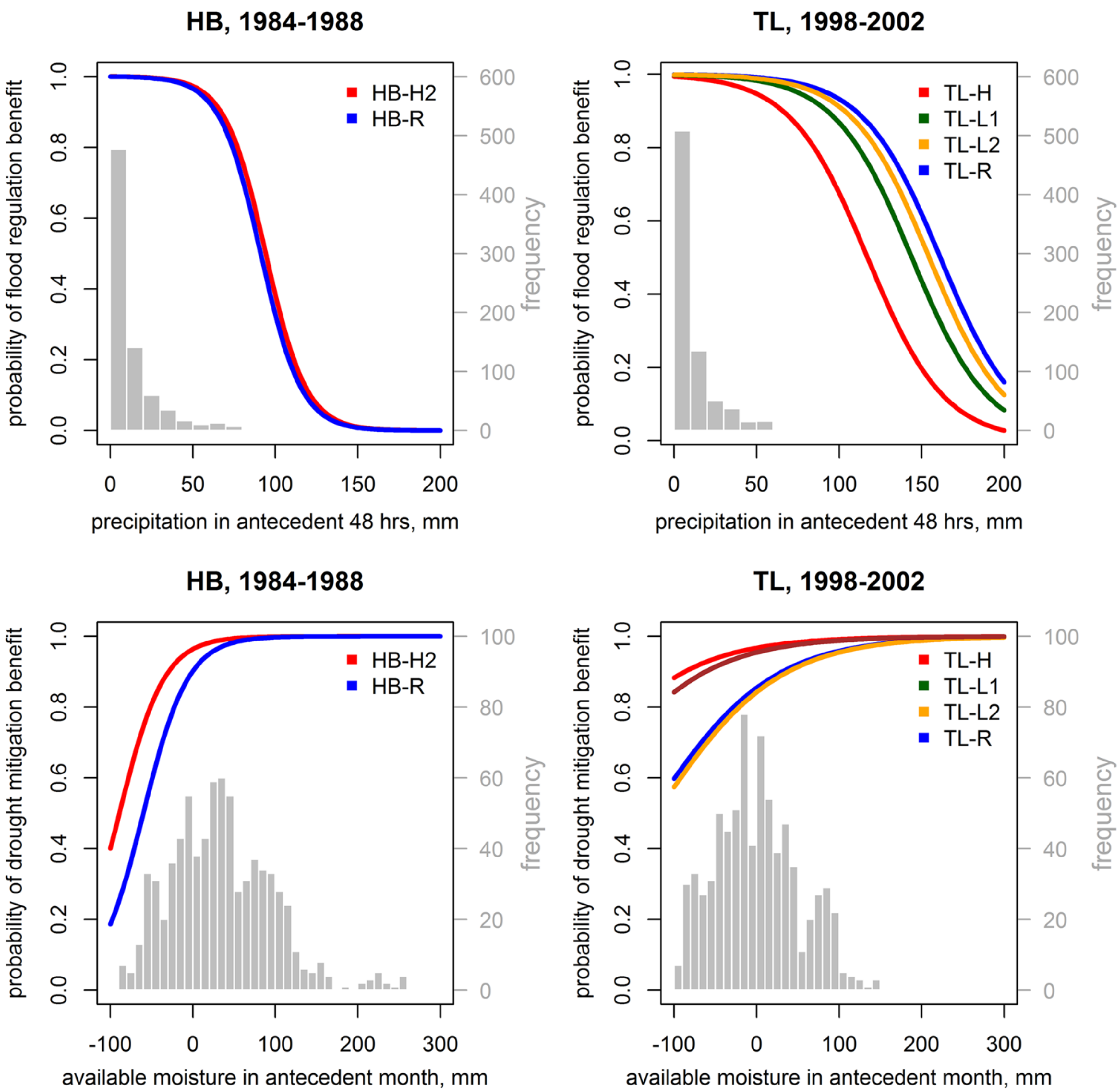


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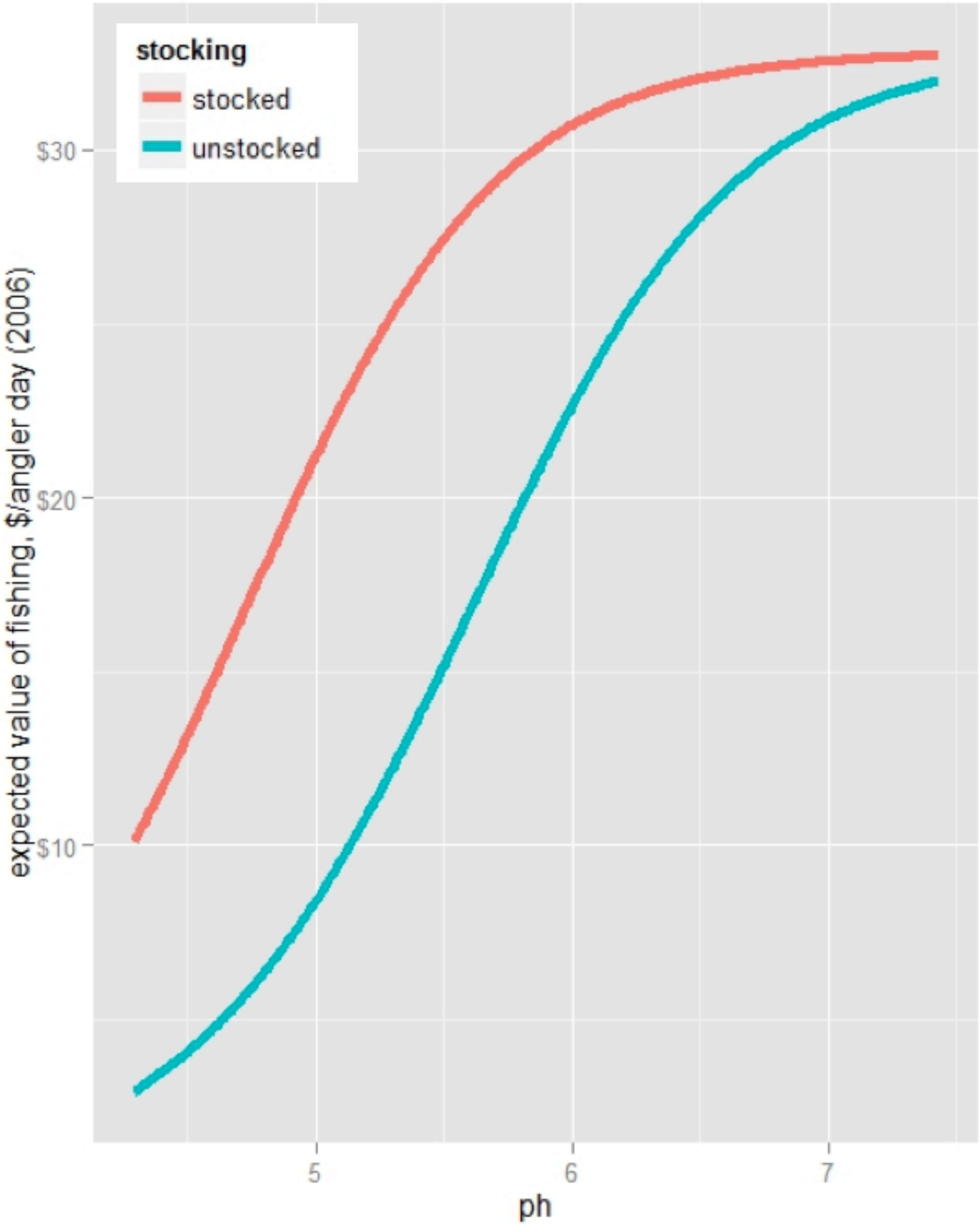
Caputo et al. 2015 Ecosystems

**Changes** in flow regulation benefits are typically **greater** with **more intensive** harvests

What about other types of monitoring? Other services?

**Salvelinus fontinalis**

# Impacts of acidification and recovery on sport fishery value in Adirondack lakes




Estimated value of sport-fishing (2006 USD) as a function of lake pH and stocking history (of trout)

ADIRONDACK LAKES SURVEY CORPORATION
www.adirondacklakessurvey.org

ALSC provided fish capture and pH data for 55 Adirondack lakes and ponds

Logistic models used to predict likelihood of trout vs. other sport fish based on pH and whether the lake was ever stocked

Benefit transfer data from Boyle (1999) to estimate expected value of a freshwater fishing trip, based on fish species present

Provides a conservative estimate of economic damages (lost value) to sport fisheries resulting from acid rain...

... and the potential benefits of recovery, via emissions caps, stocking, liming, etc.

Caputo et al. in press *Environmental Science & Technology*

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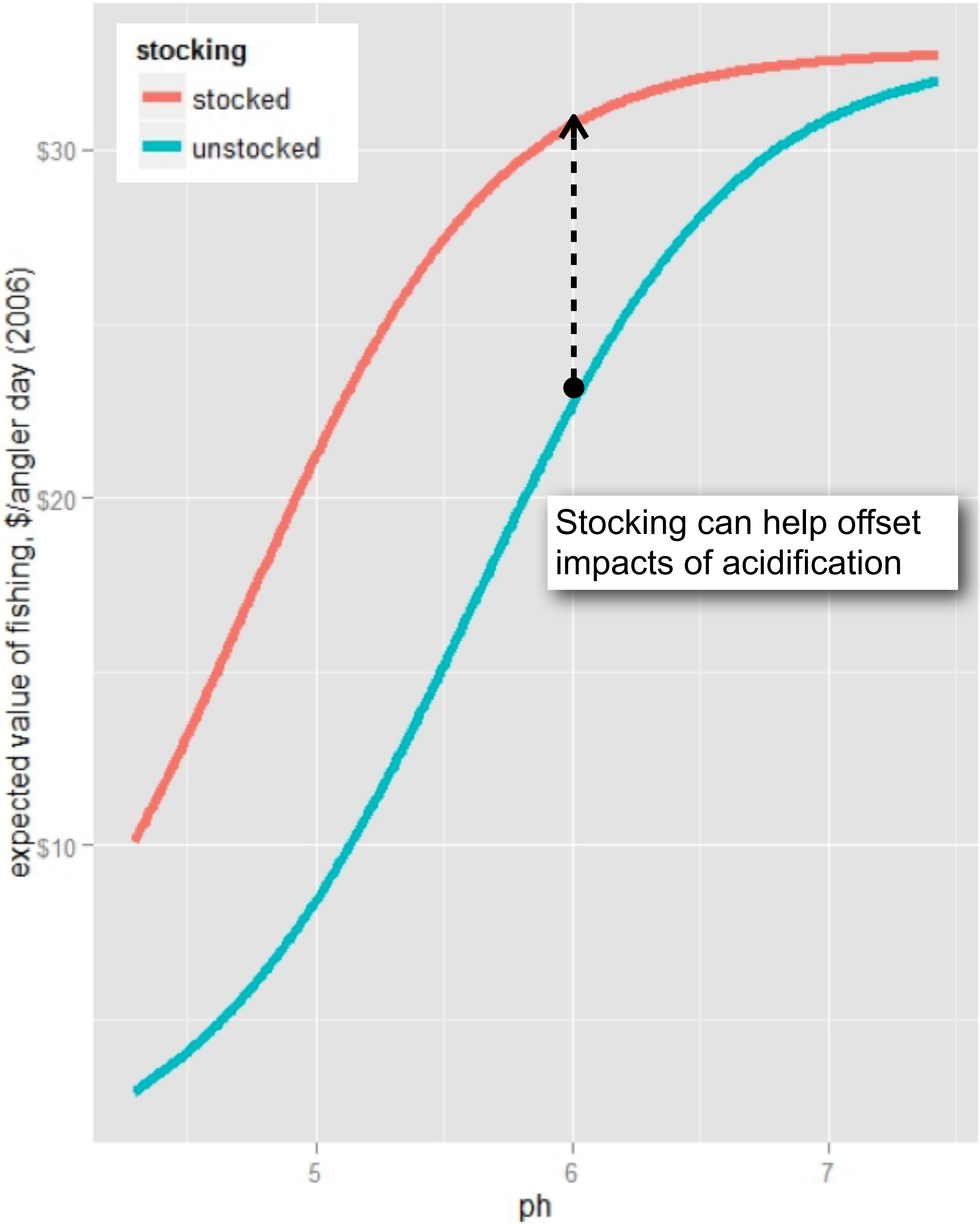


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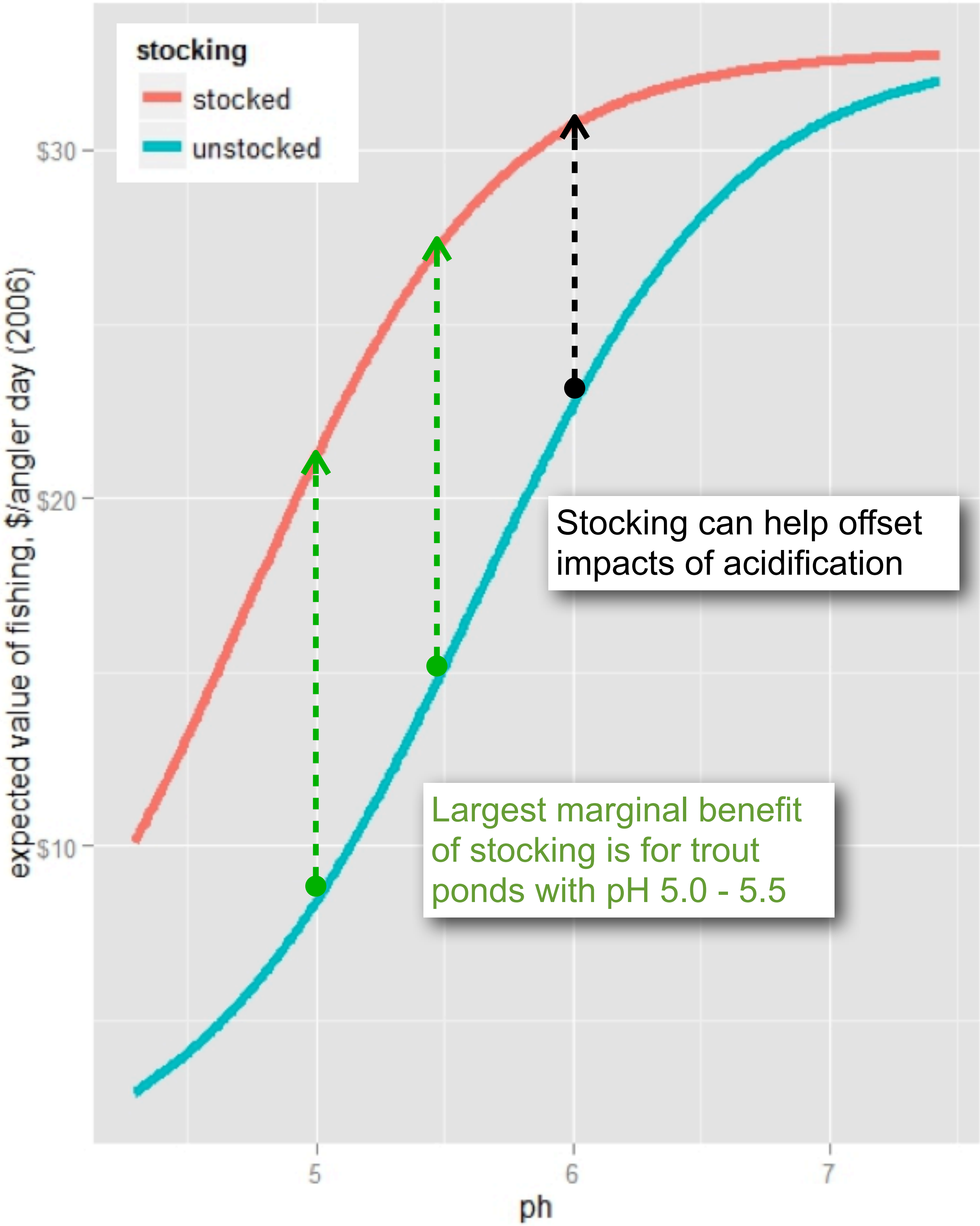


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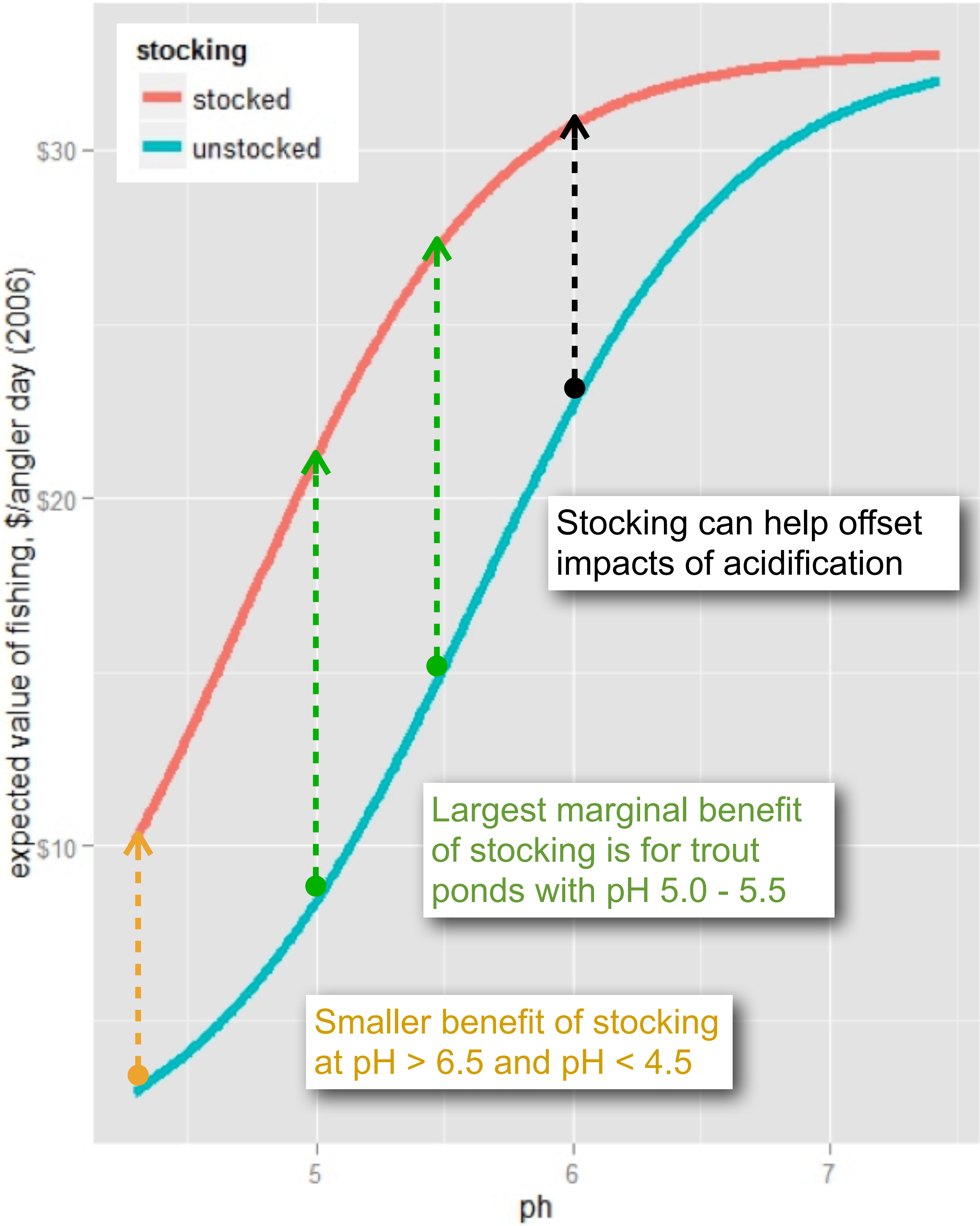


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# Monitoring change:  trends, thresholds, and complexity


**Forest Management** – FEST draws on monitoring of short and long-term ecosystem responses to forest management. Changes in services before / after harvest, and between managed / reference watersheds, provide temporally explicit estimates of changes (ΔES) attributable to silvicultural practices and related forms of land use.

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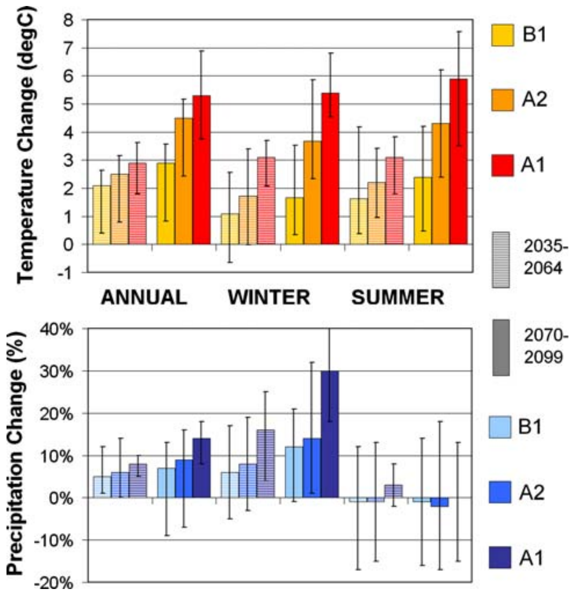


Hayhoe et al. 2007 Clim Dyn

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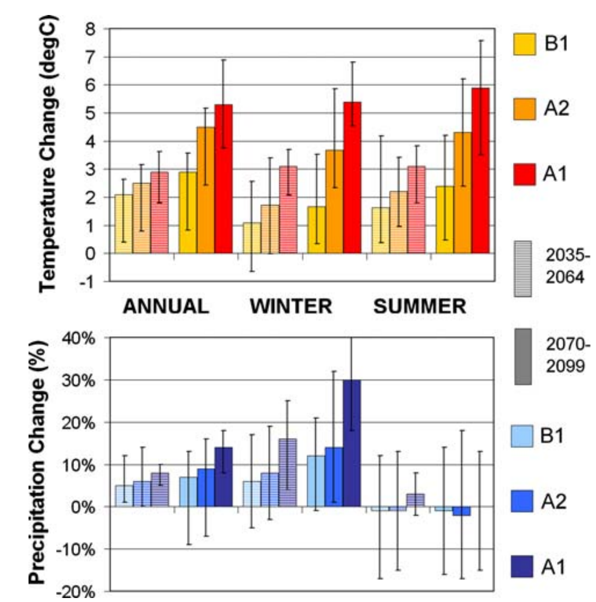

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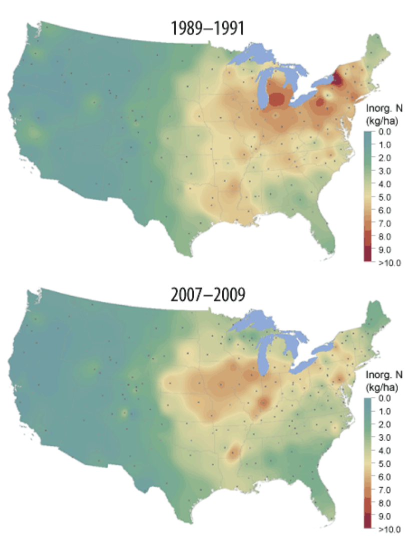


**Deposition** – Changing emissions patterns and pollutant inputs to watersheds will shape the functional loadings on forest ecosystems, increasing or decreasing the stress placed on the capacity of the system to absorb pollutants and maintain regulation of water quality and related ES. Interactions between deposition patterns and forest regeneration affects the impact of forest management on service provision.

# Thanks.


## Funding sponsors and collaborators

- US Forest Service Northeastern States Research Cooperative
- NY State Energy Research and Development Authority
- 2012 FEST Workshop Participants at Cary Inst. of Ecosystem Studies
- Hubbard Brook: Amey Bailey, Don Buso, Gene Likens, Scott Bailey
- Frost Valley: Doug Burns
- Turkey Lakes: Fred Beall
- Adirondack Lake Survey Corporation (ALSC)
- Greg Lawrence & Tim Sullivan
- Peter Groffman
- Charley Driscoll
- Frontier Spatial LLC
- Spatial Informatics Group
- OpenGeo, Project R

ESF State University of New York College of Environmental Science and Forestry

Syracuse University Founded AD 1870

E&S Environmental Chemistry, Inc.

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