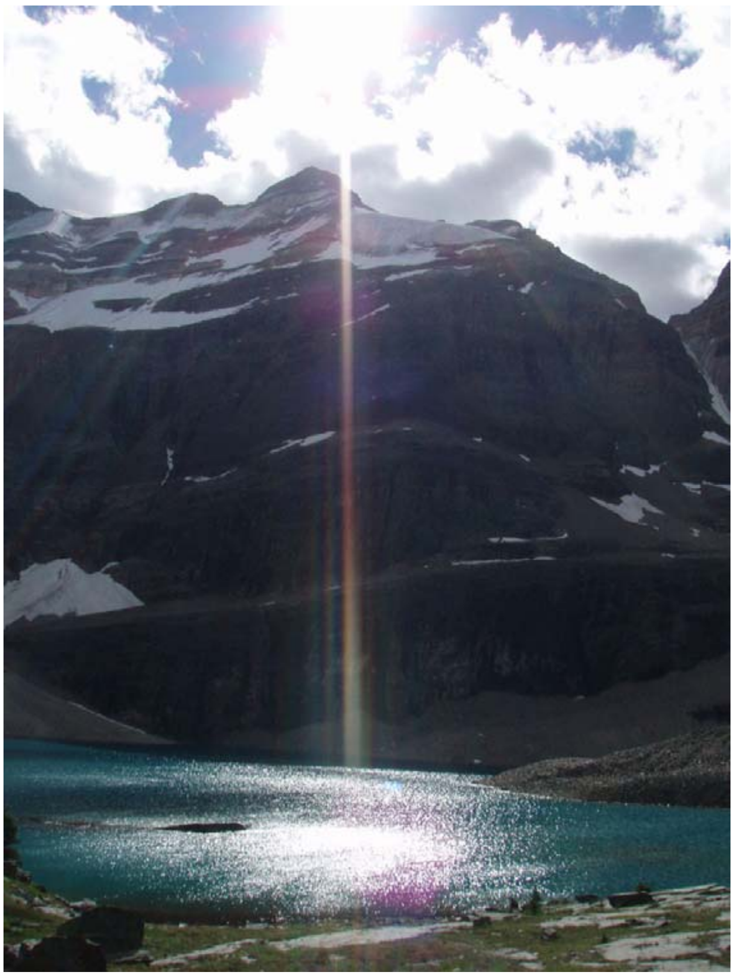
Lakes and Reservoirs as Sentinels, Integrators, and Regulators of Climate Change



8-10 September 2008
Incline Village, Nevada, USA

Chapman Conference on Lakes and Reservoirs as Sentinels, Integrators, and Regulators of Climate Change

Conveners

- **Craig Williamson,** Miami University (United States)
- **Jasmine Saros,** University of Maine Climate Change Institute (United States)

Program Committee

- **Craig Williamson**, Miami University (United States)
- **Jasmine Saros**, University of Maine Climate Change Institute (United States)
- **Rita Adrian**, IGB, Leibniz-Institute of Freshwater Ecology and Inland Fisheries (Germany)
- **John Hobbie**, Marine Biological Laboratory (United States)
- **Peter Leavitt**, University of Regina (Canada)
- **Murray MacKay**, Environment Canada
- **Diane McKnight**, University of Colorado at Boulder (United States)
- **John Melack**, University of California, Santa Barbara (United States)
- **Patrick Neale**, Smithsonian Environmental Research Center (United States)
- **David Schindler**, University of Alberta (Canada)
- **Geoff Schladow**, University of California, Davis (United States)
- **Lars Tranvik**, Uppsala University (Sweden)

Working Groups

1. **Lakes and reservoirs as sentinels of present climate change**
   Working Group Chair: Rita Adrian, IGB, Leibniz-Institute of Freshwater Ecology and Inland Fisheries (Germany)
   Co-chairs and Rapporteurs: Horacio Zagarese, Instituto Tecnológico de Chascomús (Argentina) and Catherine O'Reilly, Bard College (United States)
2. **Lakes and reservoirs as integrators of past climate change**
   Working Group Chair: Peter Leavitt, University of Regina (Canada)
   Rapporteur: Sheri Fritz, University of Nebraska (USA)
3. **Lakes and reservoirs as regulators of future climate change**
   Working Group Chair: Lars Tranvik, Uppsala University (Sweden)
   Rapporteur: John Downing, Iowa State University (USA)
4. **Scaling and modeling the role of lakes and reservoirs in climate change**
   Working Group Chair: Murray MacKay, Environment Canada
   Rapporteur: Patrick Neale, Smithsonian Environmental Research Center (USA)

Cosponsors

- Hydro-Québec
- Miami University
- NASA Mars Program Office
- NASA Mars Fundamental Research
- National Science Foundation
- Tahoe Environmental Research Center
- University of Maine Climate Change Institute

Cover Image: Lake Oesa, Yoho National Park, Canada
Alpine lakes are sensitive sentinels of climate change.
Credit: Craig Williamson

Meeting at a Glance

Sunday, 7 September, 2008

7:00 p.m. – 9:00 p.m.	Welcome Reception

Monday, 8 September 2008

7:30 a.m. – 4:30 p.m.	Registration/Information Desk
7:30 a.m. – 8:30 a.m.	Breakfast On Own
8:30 a.m. – 9:00 a.m.	Conference Welcome
9:00 a.m. – 9:40 a.m.	Keynote Presentation
9:40 a.m. – 10:20 a.m.	Sentinels Working Group Synthesis Presentation
10:20 a.m. – 11:00 a.m.	Integrators Working Group Synthesis Presentation
11:00 a.m. – 11:30 a.m.	Refreshment Break
11:30 a.m. – 12:10 p.m.	Regulators Working Group Synthesis Presentation
12:10 p.m. – 12:50 p.m.	Modeling Working Group Synthesis Presentation
12:50 p.m. – 2:30 p.m.	Lunch On Own
2:30 p.m. – 3:10 p.m.	Keynote Presentation
3:10 p.m. – 4:30 p.m.	Working Group Meetings
4:30 p.m. – 6:30 p.m.	Poster Session (Sentinels and Integrators)

Tuesday, 9 September 2008

8:00 a.m. – 4:30 p.m.	Registration/Information Desk
7:30 a.m. – 8:30 a.m.	Breakfast On Own
8:30 a.m. – 9:10 a.m.	Keynote Presentation
9:10 a.m. – 10:30 a.m.	Plenary Session: Working Group Updates and Discussion
10:30 a.m. – 11:00 a.m.	Refreshment Break
11:00 a.m. – 12:30 p.m.	Working Group Meetings
12:30 p.m. – 2:00 p.m.	Lunch On Own
2:00 p.m. – 2:40 p.m.	Keynote Presentation
2:40 p.m. – 4:30 p.m.	Working Group Meetings
4:30 p.m. – 6:30 p.m.	Poster Session (Regulators and Modeling)

Wednesday, 10 September 2008

8:00 a.m. – 4:30 p.m.	Registration/Information Desk
7:30 a.m. – 8:30 a.m.	Breakfast On Own
8:30 a.m. – 9:10 a.m.	Keynote Presentation
9:10 a.m. – 10:30 a.m.	Plenary Session: Working Group Updates and Discussion
10:30 a.m. – 11:00 a.m.	Refreshment Break
11:00 a.m. – 12:30 p.m.	Working Group Meetings
12:30 p.m. – 2:00 p.m.	Lunch On Own
2:00 p.m. – 2:40 p.m.	Keynote Presentation
2:40 p.m. – 4:30 p.m.	Working Group Meetings
4:30 p.m. – 5:30 p.m.	Conference Closing and Discussion
6:30 p.m.	Conference Dinner and Social

Program Overview

Sessions and events will take place at the Thomas J. Long Education Center, Tahoe Center for Environmental Sciences (TERC) and the Hyatt Regency Lake Tahoe Resort, Spa and Casino. The Registration/Information Desk will be in TERC throughout the conference.

SUNDAY, 7 SEPTEMBER

7:00 p.m. – 9:00 p.m. ♦ **Welcome Reception** ♦ Hyatt, Lakeside A
All meeting attendees are invited to attend this kick-off event. Enjoy a relaxing evening with friends and colleagues. Complimentary hors d'oeuvres will be provided and drinks will be available for purchase.

MONDAY, 8 SEPTEMBER

7:30 a.m. – 8:30 a.m. ♦ **Breakfast**
Attendees are on their own for breakfast.

8:30 a.m. – 9:00 a.m. ♦ **Welcome and Open Remarks** ♦ TERC, Room 139
Convener: Craig Williamson

9:00 a.m. – 9:30 a.m. ♦ **Keynote Presentation** ♦ TERC, Room 139
L G Thompson, *Global Climate Change: A Paleoclimate Perspective from the World's Highest Mountains*

9:30 a.m. – 9:40 a.m. ♦ **Questions and Discussion** ♦ TERC, Room 139

9:40 a.m. – 10:10 a.m. ♦ **Sentinels Working Group Synthesis Presentation** ♦ TERC, Room 139
Working Group Chair: R Adrian, *Lakes and Reservoirs as Sentinels of Present Climate Change*

10:10 a.m. – 10:20 a.m. ♦ **Questions and Discussion** ♦ TERC, Room 139

10:20 a.m. – 10:50 a.m. ♦ **Integrators Working Group Synthesis Presentation** ♦ TERC, Room 139
Working Group Chair: P R Leavitt, *Paleolimnological Evidence of Modes and Mechanisms of Climate Variability and Effects on Lakes*

10:50 a.m. – 11:00 a.m. ♦ **Questions and Discussion** ♦ TERC, Room 139

11:00 a.m. – 11:30 a.m. ♦ **Refreshment Break** ♦ TERC, Room 139

11:30 a.m. – 12:00 p.m. ♦ **Regulators Working Group Synthesis Presentation** ♦ TERC, Room 139
Working Group Chair: L J Tranvik, *Lakes and Reservoirs as Regulators of Future Carbon Cycling and Climate*

12:00 p.m. – 12:10 p.m. ♦ **Questions and Discussion** ♦ TERC, Room 139

12:10 p.m. – 12:40 p.m. ♦ **Modeling Working Group Synthesis Presentation** ♦ TERC, Room 139
Working Group Chair: M D MacKay, *Scaling and Modeling the Role of Lakes and Reservoirs in Climate Change*

12:40 p.m. – 12:50 p.m. ♦ **Questions and Discussion** ♦ TERC, Room 139

12:50 p.m. – 2:30 p.m. ♦ **Lunch Break**
Attendees are on their own for lunch.

2:30 p.m. – 3:00 p.m. ♦ **Keynote Presentation** ♦ TERC, Room 139
J E Saros, *Lakes as Sentinels and Integrators of Climate Change: Identifying Key Mechanisms by Merging Experimental and Paleolimnological Approaches*

3:00 p.m. – 3:10 p.m. ♦ **Questions and Discussion** ♦ TERC, Room 139

3:10 p.m. – 4:30 p.m. ♦ **Working Group Meetings**
- Integrators ♦ Hyatt, Castle Peak A
- Modeling ♦ Hyatt, Castle Peak B
- Regulators ♦ TERC, Room 141
- Sentinels ♦ TERC, Room 139

4:30 p.m. – 6:30 p.m. ♦ **Poster Session** ♦ Hyatt, Regency D
Posters from the Sentinels and Integrators working groups will be presented during this session. Take this opportunity to view these posters and interact with colleagues. Beverages will be available for purchase.

TUESDAY, 9 SEPTEMBER

7:30 a.m. – 8:30 a.m. ♦ **Breakfast**
Attendees are on their own for breakfast.

8:30 a.m. – 9:00 a.m. ♦ **Keynote Presentation** ♦ TERC, Room 139
C R Goldman, *Lake Tahoe: Five Decades of Change and the World Water Crisis*

9:00 a.m. – 9:10 a.m. ♦ **Questions and Discussion** ♦ TERC, Room 139

9:10 a.m. – 10:30 a.m. ♦ **Working Group Updates and Open Discussion** ♦ TERC, Room 139
Rapporteurs: Sheri Fritz (Integrators); Patrick Neale (Modeling); John Downing (Regulators); Horacio Zagarese and Catherine O'Reilly (Sentinels)

10:30 a.m. – 11:00 a.m. ♦ **Refreshment Break** ♦ TERC, Room 139

11:00 a.m. – 12:30 p.m. ♦ **Working Group Meetings**
- Integrators ♦ Hyatt, Castle Peak A
- Modeling ♦ Hyatt, Castle Peak B
- Regulators ♦ TERC, Room 141
- Sentinels ♦ TERC, Room 139

12:30 p.m. – 2:00 p.m. ♦ **Lunch Break**
Attendees are on their own for lunch.

2:00 p.m. – 2:30 p.m. ♦ **Keynote Presentation** ♦ TERC, Room 139
M Winder, *Climate Effects on Lake Ecosystems: Lessons From Historical Time Series*

2:30 p.m. – 2:40 p.m. ♦ **Questions and Discussion** ♦ TERC, Room 139

2:40 p.m. – 4:30 p.m. ♦ **Working Group Meetings**

- Integrators ♦ Hyatt, Castle Peak A
- Modeling ♦ Hyatt, Castle Peak B
- Regulators ♦ TERC, Room 141
- Sentinels ♦ TERC, Room 139

4:30 p.m. – 6:30 p.m. ♦ **Poster Session** ♦ Hyatt, Regency D
Posters from the Regulators and Modeling working groups will be presented during this session. Take this opportunity to view these posters and interact with colleagues. Beverages will be available for purchase.

WEDNESDAY, 10 SEPTEMBER

7:30 a.m. – 8:30 a.m. ♦ **Breakfast**
Attendees are on their own for breakfast.

8:30 a.m. – 9:00 a.m. ♦ **Keynote Presentation** ♦ TERC, Room 139
D W Schindler, *Effects of Climate Change on Lake-Watershed Interactions*

9:00 a.m. – 9:10 a.m. ♦ **Questions and Discussion** ♦ TERC, Room 139

9:10 a.m. – 10:30 a.m. ♦ **Working Group Updates and Open Discussion** ♦ TERC, Room 139
Rapporteurs: Sheri Fritz (Integrators); Patrick Neale (Modeling); John Downing (Regulators); Horacio Zagarese and Catherine O'Reilly (Sentinels)

10:30 a.m. – 11:00 a.m. ♦ **Refreshment Break** ♦ TERC, Room 139

11:00 a.m. – 12:30 p.m. ♦ **Working Group Meetings**

- Integrators ♦ Hyatt, Castle Peak A
- Modeling ♦ Hyatt, Castle Peak B
- Regulators ♦ TERC, Room 141
- Sentinels ♦ TERC, Room 139

12:30 p.m. – 2:00 p.m. ♦ **Lunch Break**
Attendees are on their own for lunch.

2:00 p.m. – 2:30 p.m. ♦ **Keynote Presentation** ♦ TERC, Room 139
W J Palen, *Predicting Species and Community Responses to Accelerated Global Change; What We've Learned From Montane Lakes and Ponds*

2:30 p.m. – 2:40 p.m. ♦ **Questions and Discussion** ♦ TERC, Room 139

2:40 p.m. – 4:30 p.m. ♦ **Working Group Meetings**

- Integrators ♦ Hyatt, Castle Peak A
- Modeling ♦ Hyatt, Castle Peak B
- Regulators ♦ TERC, Room 141
- Sentinels ♦ TERC, Room 139

4:30 p.m. – 5:30 p.m. ♦ **Final Wrap-Up Discussion and Synthesis** ♦ TERC, Room 139

6:30 p.m. ♦ **Conference Dinner and Social** ♦ Hyatt, Lower Cottage Green
Join your colleagues and friends as we wrap-up the conference. Participants will enjoy a scenic view during this outdoor barbeque and social event.

Poster Sessions

In addition to the first author and abstract title, each listing begins with the poster number used during the poster viewing sessions on Monday and Tuesday evenings.

Note: An asterisk after an author's name denotes the first author is a student.

INTEGRATORS WORKING GROUP

I-01 • N J Anderson, *Lake Ecosystem Response to Natural Climate Forcing Indicated by Diatom Analysis of Varved Lake Sediments*

I-02 • P A Baker, *Constraining Precipitation Variation in the Tropical Andes Using Lacustrine Sedimentary Records*

I-03 • *H M Baulch, *Lakes as Nutrient Sinks: Does Climate Mediate Nitrogen and Phosphorus Retention?*

I-04 • *L Bunting, *Climatic Regulation of Nitrogen Influx to Lakes in Alpine Catchments*

I-05 • J Catalan, *Climate and CO2-Saturation Throughout the Holocene in the Pyrenean Lakes*

I-06 • D J Conley, *Ecosystem Thresholds in Lakes in Response to Climate Change*

I-07 • M B Edlund, *Using Paleolimnological Records to Separate Impacts of Management, Land-use, and Climate in US National Park Lakes*

I-08 • *W. O. Hobbs, *Quantifying Limnological Change in the Anthropocene: A Comparison of High-Altitude and High-Latitude Ecosystems*

I-09 • S McGowan, *Flooding as a Driver of Lake Primary Production Over the Past 120 Years in Lakes of the Peace Athabasca Delta, Northern Alberta, Canada*

I-10 • P A Meyers, *38 ky Record of the East Asian Monsoon from Sediments of Lake Biwa, Japan*

I-11 • G L Simpson, *Deciphering the Effect of Climate Change and Separating the Influence of Confounding Factors in Sediment Core Records Using Generalised Additive Models*

I-12 • N Solovieva, *Biotic Responses to 20th Century Climate Change in Arctic and Subarctic Lakes Along Vegetation Gradient from the Northern Urals to Western Siberia*

I-13 • R D Vinebrooke, *Context Dependency of Climate Warming Impacts on Alpine Lakes*

I-14 • K Y Wei, *Drastic Aridification of Southern Xinjiang, Northwestern China, in the end of the 8th Century: Geochemical and Ostracod Evidence from Lake Bosten*

I-15 • J P Werne, *Molecular and Isotopic Evidence for Climate-Induced Changes in the Algal Community and Primary Production in Lake Malawi (East Africa) During the Past 23,000 Years*

MODELING WORKING GROUP

M-01 • C D Arp, *Spatial and Temporal Dynamics of Lake Ice on the Arctic Coastal Plain of Alaska*

M-02 • T J Ballatore, *The Likely Effects of Climate Change on Lakes in the Endorheic Basins of Africa Through 2100*

M-03 • L N De Senerpont Domis, *Nutrient Loading and Climate Warming: two Synergetic Drivers of Freshwater Algal Dynamics?*

M-04 • X Fang, *Simulations of Climate Effects on Water Temperature, Dissolved Oxygen, Ice/Snow Covers, and Fish Habitat in Lakes of the Contiguous USA under Past and Future Climate Scenarios*

M-05 • G Gal, *Modeling the Differential Effect of Climate Change on Monomictic Lake Ecosystems in Contrasting Climatic Regions: Southern Temperate (N.Z.) vs Sub-Tropical (Israel)*

M-06 • P C Hanson, *Lakes as Sensors of OC Perturbations in the Landscape*

M-07 • K D Jöhnk, *Climate Change Impacts on Lake Stratification – A Large Scale Simulation Approach*

M-08 • G Kirillin, *Shallow Lake Response to Climate Change: the Role of the Heat Storage by Sediments*

M-09 • P J Kushner, *Uncertainty in the Boreal Lake Region Response to Climate Change*

M-10 • E Litchman, *Modeling Phytoplankton Community Re-organizations Under Global Change*

M-11 • J C Little, *Effect of Climate-Driven Changes in Wind, River Inflow, and Air Temperature on the Stability of a Small-to-Medium Sized Lake*

M-12 • D M Livingstone, *Irregular "Sawtooth" Events in Long Time-Series of Deep-Water Temperature*
M-13 • S MacIntyre, *Arctic Lakes are Seives: Will Climate Warming Close the Pores?*
M-14 • P Marsh, *Hydrology of, and Turbulent Fluxes From, Lakes in a Tundra Setting*
M-15 • F Peeters, *Modeling Changes in the Frequency of Ice Cover on Lakes*
M-16 • A Quesada, *Polar Lakes From Antarctic Peninsula as Sensors of Rapid Climate Change*
M-17 • S. G. Schladow, *Mechanisms and Consequences of Climate Change on Thermal Stratification in a Deep Lake*
M-18 • M Schmid, *Effects of a Changing Climate on the Stability of Lakes and Reservoirs: Causes and Consequences*
M-19 • C Spence, *Evaporative Fluxes from Lake Superior*
M-20 • S L Stokes, *Lake James Assessment: Water Balance and Chemical Budget Models Developed in STELLA for the Water Quality Dynamics of Lake James in the Catawba River Basin of North Carolina*
M-21 • C Teodoru, *Integrating the Stream, River and Lake Components of CO2 Fluxes to the Atmosphere in Quebec's Boreal Region*

Regulators Working Group

R-01 • D S Abe, *Deposition Rates of Carbon, Nitrogen, Phosphorus and Greenhouse Gas Emissions as a Consequence of Eutrophication in the Reservoirs in the Middle Tietê River, Southeastern Brazil*
R-02 • M Aurelio dos Santos, *The Long Range Flooding Effect of Reservoirs in Tropical Environment*
R-03 • J B Cotner, *Prairie Pothole Lakes in North America: Indicators of the Past and Predictors of the Future Carbon Storage in Shallow Lakes*
R-04 • P J Dillon, *Dissolved Organic Matter: Long-term Changes in Fluxes, Concentrations and Retention*
R-05 • *F Domínguez-Castro, *Detailed Estimation of the C Accumulation Fluxes at Las Tablas de Daimiel National Park (Spain) for the Last 1000 Years and how are Influenced by Climate and Anthropogenic Activities*
R-06 • K Finlay, *Climatic and Chemical Regulation of CO2 Flux in Hardwater Prairie Lakes*
R-07 • *K Fortino, *Organic Matter Burial in Arctic Lake Sediments: The Effect of Temperature, Oxygen Availability, and Autochthony*
R-08 • *L B Knoll, *Reservoir Carbon Budgets Mediated by Land Use and Precipitation Variability*
R-09 • P Kortelainen, *Carbon Evasion/Accumulation in Randomly Selected Boreal Lakes Located Between Latitudes 60o N and 69o N*
R-10 • T Kutser, *Variations in Colored Organic Matter in Lakes Studied by Satellite Remote Sensing Across Regions and Climates*
R-11 • I Laurion, *Greenhouse Gas Emission by Thermokarst Ponds: Microbial Assemblages, Dissolved Organic Matter and Other Controlling Factors*
R-12 • D M Leech, *Climate Change and DOM Photomineralization: Implications for Lake CO2 Evasion*
R-13 • S A Loiselle, *Dissolved Organic Matter, Regulators and Indicators of Bio-optical Conditions in Tropical and Subtropical Lakes*
R-14 • J A Lorenzzetti, *CO_2 and CH_4 Emissions in Tropical Brazilian Hydroelectric Reservoirs**: The Effect of Meteorological Systems*
R-15 • S L McCallister, *Evidence for the Respiration of Ancient Terrestrial Organic C in Northern Temperate Lakes: Implications for the Terrestrial C Budget*
R-16 • E P Overholt, *Reservoirs as Sentinels and Integrators of Climate Change: Using Optical Tools*
R-17 • J A Porter, *Reactivity of Terrestrially Derived Dissolved Organic Matter in the Aquatic Ecosystem: Investigating Issues of Source, Biolability, Photolability and Nutrient Composition*
R-18 • W Renwick, *Effects of Reservoir Sedimentation on the Global Carbon Budget*
R-19 • F Roland, *Spatial Variation in CO2 Flux From Large Freshwater Systems: Tropical Hydroelectric Reservoirs*
R-20 • R W Sanders, *Dissolved Organic Carbon (DOC) Forcing of Plankton Dynamics in a Lake Ecosystem*
R-21 • C Sidagis-Galli, *Methane Path From Sediment to Atmosphere in Tropical Hydroelectric Reservoirs*

R-22 • S Sobek, *High Organic Carbon Burial Efficiencies in Lake Sediments: Relationships with Oxygen Exposure Time and Mineral Phase Properties*
R-23 • R G Striegl, *Water and Isotope Chemistry and Carbon Dynamics Along a Lake Evaporation Gradient in Yukon Flats, Alaska*
R-24 • A Tremblay, *15 Years of Greenhouse Gases Measurements From Boreal Hydroelectric Reservoirs and Lakes: Are They Different?*
R-25 • *E von Wachenfeldt, *Flocculation of Allochthonous Organic Carbon – A Regulator of Organic Carbon Burial in Boreal Lakes?*
R-26 • Y L Zhang, *Photodegradation of Chromophoric Dissolved Organic Matter Exposed to Simulated UV and Natural Solar Radiation*

SENTINELS WORKING GROUP

S-01 • J A Austin, *Thermal and Hydrological Impacts of Increased Wind Speed on Lake Superior*
S-02 • S B Baines, *Will Zebra Mussels Alter the Response of Ecosystems to Increasing DOM Supply*
S-03 • B Boehrer, *Higher Air Temperatures Affecting the Probability for Meromixis*
S-04 • R N Coats, *Climate Change in the Tahoe Basin: Impacts and Drivers*
S-05 • *D Coenen, *Interannual Lake Temperature Trends as Indicators for Recent Climatic Change in Peninsular Florida*
S-06 • S L Cooke, *Effects of Increased Dissolved Organic Matter on Zooplankton Vertical Distribution in a UV-Transparent Lake: Results From Large-Scale Mesocosms*
S-07 • D da Motta Marques, *Lakes as Sensors of Landscape and Climate Change: A Global Sensor Web*
S-08 • M C Diéguez, *Synergetic Effects of UV Radiation and Temperature in Cold-Adapted Calanoid Copepods From Patagonia (Argentina): Bioaccumulation of Photoprotective Compounds and Mortality Trends*
S-09 • *I Dröscher, *Climate Control of Spring Clear-Water Phase Development Through the Transfer of Energy and Mass to Lakes*
S-10 • *M D Graham, *Climate Extremes Alter Northern Lake Food Webs*
S-11 • A W Groeger, *Influence of Changing Climate on Subtropical Reservoirs*
S-12 • S E Hampton, *Long-term Warming and Deepening Summer Phytoplankton Distribution in Lake Baikal, Siberia*
S-13 • D O Hessen, *Nitrogen Deposition, Catchment Carbon Export and Climate as Determinants of Lake Stoichiometry*
S-14 • J E Hobbie, *Measures and Changes in an Arctic Lake in Alaska: Chemical Changes as Indicators of Climate Change in a Sentinel Lake*
S-15 • *V Huber, *Contrasting Development of Cyanobacteria Blooms During two Summer Heat Waves*
S-16 • L R Izmest'eva, *Climate Change and Phytoplankton Community Structure in Lake Baikal, Siberia*
S-17 • E Jeppesen, *Top-Down and Bottom-Up Control Strongly Affected by Global Warming in North Temperate Lakes*
S-18 • J Karlsson, *Lake Productivity and Biostructure along a Climate Gradient in Northern Sweden*
S-19 • Y A Kontar, *A Study of the Subsurface Water Role in Water Resources of Lake Michigan: Ecological Policy, Assessment and Prediction*
S-20 • A Korhola, *Searching for Critical Thresholds for Mid-Summer Breakdown of Thermal Stratification in Subarctic Lakes of Finnish Lapland*
S-21 • T K Kratz, *The Global Lakes Ecological Observatory Network: Facilitating the Coupling of Observations and Models Across a Global Gradient of Lakes*
S-22 • *S Larsen, *Principal Catchment Specific Determinants for Organic Carbon in Norwegian Lakes*
S-23 • J D Lenters, *Response of a North Temperate Lake to Interannual and Long-term Variations in Climate: Compounding Effects of Temperature, Cloud Cover, and Humidity*
S-24 • *M E Llames, *Light Availability as a Useful Paradigm for Understanding Shallow Lake Functioning and Future Responses to Climate Change*
S-25 • M M Manca, *Increase in Bythotrephes in Lake Maggiore as Mediated by Refuge Increase Due to Climate Warming*

S-26 • B Matthews, *The Structure of Plankton Food Webs Along Environmental Gradients*
S-27 • A Mazumder, *Climate Change Induces Nitrogen Loading From Terrestrial to Aquatic Ecosystems*
S-28 • J M Melack, *Ecological Responses to Three Decades of Climate Variability in Sierra Nevada Lakes*
S-29 • N Mladenov, *Tracing Organic Matter From Dust Deposition Into Alpine Lakes Using Fluorescence Fingerprinting*
S-30 • D R Mueller, *Climate-Driven Regime Shifts in High Arctic Ice-Covered Lakes*
S-31 • P J Neale, *Effects of High CO2 Concentrations Under UVR Exposures on Natural Phytoplankton Assemblages From a Lake*
S-32 • M H Olson, *Implications of Changing Temperature and Ultraviolet Radiation Regimes for Reproductive Success of Temperate Fishes*
S-33 • J Oris, *Dissolved Organic Matter and Ultraviolet Radiation as Sentinels of Landscape-Scale Climate Change*
S-34 • A M Paterson, *Assessing Impacts of Climate Change on Boreal Shield Lakes in a Multiple Stressor Environment*
S-35 • S Pham, *Spatial and Temporal Variability of Prairie Lake Hydrology as Revealed Using Stable Isotopes of Hydrogen and Oxygen*
S-36 • *K C Rose, *The Development of an Optical Indicator of Allochthony in Low DOM Lakes*
S-37 • *C R Salm, *Alpine Lakes as Sentinels of Climate Change: Investigating the Effects of Ultraviolet Radiation and Temperature on Plankton Dynamics*
S-38 • *R L Smyth, *Climate Change Implications for Disease Ecology in Small Temperate Lakes*
S-39 • R Sommaruga, *Consequences of Glacier Retreat for the Planktonic Food Web Structure and Function of Alpine Lakes*
S-40 • D Straile, *Effects of a Half-A-Millennium Winter on a Large Lake – A Shape of Things to Come?*
S-41 • *A Tucker, *Temperature and Ultraviolet Radiation Interact to Control Invasive Warm-water Fishes*
S-42 • P Verburg, *Climate Warming Slowed Down the Nitrogen Cycle in Lake Tanganyika*
S-43 • A M Verschoor, *Effects of Elevated CO2 Concentrations on Phytoplankton Biomass, Elemental Composition, and Species Composition*
S-44 • *C Wagner, *Long Term Changes in Lake Ecosystems: The Question of When and How?*
S-45 • *R P Weidman, *Climate Change and the Phenological Plasticity of Zooplankton in Mountain Lakes*
S-46 • G A Weyhenmeyer, *Nonlinear Response of Dissolved Organic Carbon in Lakes to Global Warming*

Abstracts

Deposition Rates of Carbon, Nitrogen, Phosphorus and Greenhouse Gas Emissions as a Consequence of Eutrophication in the Reservoirs in the Middle Tietê River, Southeastern Brazil

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Sewage produced in large urban areas is considered as a major cause of eutrophication in the water bodies of Brazil, as the average rate of treatment in the country is only 20 %. This can be clearly seen in reservoir cascades in the middle Tietê River, located downstream from the metropolitan region of São Paulo, southeastern Brazil, which was built to generate hydropower. In a study carried out in the three former reservoirs in the dry season (October 2005) and in the rainy season (March 2006), the total organic carbon (TOC), total organic nitrogen (TON), total phosphorus (TP) and suspended organic material (SOM) deposition rates in the water column were measured using sediment traps. Methane, carbon dioxide and nitrous oxide concentrations in the sediments were measured using gas chromatography and their diffusive fluxes across the water-air interface were also measured using floating chambers. The highest deposition rates of TOC, TN, TP and TOM were observed in the Barra Bonita Reservoir, the first of the three cascade reservoirs and the most eutrophic, both in the dry season and in the rainy season. The highest deposition rates observed in this reservoir also resulted in the highest methane and nitrous oxide concentrations in the sediments and their diffusion fluxes across the water surface to the atmosphere. A decreasing trend in all these variables was observed downstream from the reservoirs, which shows a clear deputation capacity of these systems. The present study shows that bad management of the water resources results in greenhouse gas emissions to the atmosphere, probably much higher if compared to the emissions in controlled conditions of sewage treatment plants. Nevertheless, the carbon and nitrogen deposition rates from the water column to the sediments observed are much higher if compared to the emissions to the atmosphere, which means that these systems act as carbon and nitrogen sinks.

Lakes and Reservoirs as Sentinels of Present Climate Change

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We will put together most prominent changes of lake ecosystems to recent climate change to present the state of the art with respect to responses at various levels from physical (e.g. ice phenology, temperature, stratification, UV) to biological system level (e.g. phenology, plankton, macro-invertebrates). We will extract coherent versus system specific climatic signals in lakes - often linked to large scale climatic phenomena such as the NAO or EL Niño/La Niña events. We intend to include climate induced changes in phenology and subsequent mis-timings in interaction, the impact of extreme events such as heat waves or storms, climate induced changes at small temporal scale, or the role of counteracting effects. Desirable would be a paragraph on catchment effects on nutrient dynamics and DOC as modified by changes in snow cover, severity of frost or atmospheric deposition. We will include known effects in African lakes and how they differ from those found in e.g. North temperate lakes. As an outlook for future challenges, we may discuss the role of climate induced species invasion or extinction and subsequent establishments of novel freshwater communities.

Lake Ecosystem Response to Natural Climate Forcing Indicated by Diatom Analysis of Varved Lake Sediments

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Effects of climate change on contemporary ecosystems are difficult to determine because of the confounding influence of other stressors and the short timescale of contemporary monitoring. We combined diatom analysis of pre-cultural, varved sediments (176 contiguous samples each representing 5-yrs) with tree-ring inferred summer temperatures, to determine the ecological response of a boreal lake (Kassjon, northern Sweden) to natural climatic variability during a period (435 B.C. to A.D. 445) that pre-dates agriculture in the catchment. Diatom temporal variability and diversity were significantly different (determined by Levene's test) during cooler compared to warmer summer temperatures; greater climate variability culminated in a major change in diatom composition (indicated by PCA). Altered species composition, notably increases in planktonic diatoms indicative of nutrient enrichment (Asterionella formosa) and higher DOC concentration (Aulacoseira tenella), was associated with warmer temperatures and is inferred as reflecting altered catchment processes (e.g. generation of DOM within soils), i.e. indirect climate forcing. Using temperature as a covariate, however, generalized additive modelling indicated significant direct climate effects on the littoral zone (inferred from changes in benthic diatom composition) during short-term cold periods.

Spatial and Temporal Dynamics of Lake Ice on the Arctic Coastal Plain of Alaska

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Ice is a dominant attribute of Arctic lakes because most are only as deep as maximum ice thickness, such that many freeze solid. Lakes that do not freeze solid can provide winter aquatic refugia and water supply. To better understand temporal lake ice variability in a spatially-relevant context, we coupled point, ground penetrating radar, and synthetic aperture radar measurements of ice thickness with modeled ice thickness from 1971 to 2007. In May 2007, floating ice averaged 169 cm with often thicker bed-fast ice. Remotely-sensed ice measurements indicated that 52%, of 185 lakes surveyed, froze solid. Estimates of maximum annual ice growth over 39 years ranged from 153 to 198 cm and significantly thinned by 0.5 cm/yr ($r2=0.44$, $p<0.0001$), while timing of freeze onset and maximum growth showed no decadal trends. Mean monthly temperatures in October and April explained 68% of the interannual variation ($p<0.0001$) in ice-thickness. This spatial variability coupled with temporal trends will likely have profound implications for water supply, fish and waterfowl habitat, lake energy (heat and carbon) storage, and surface albedo, in a changing Arctic climate.

The Long Range Flooding Effect of Reservoirs in Tropical Environment

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The effect of flooding tropical areas is here considered on the scale beyond one century. Brazil has one large hydroelectric reservoir over one hundred years old, several over 50 and many over 30. A large number of them we studied intensely as to their carbon budgets. All of them have permanently anoxic bottoms in which detritus decomposition by methanogenesis goes on producing biologically inert humic substance which is headed for fossilization. Data from the four of them which are situated in similar latitude, close to parallel 20o S, and are 26 to 50 years old, show that permanent carbon sinking, typically 137 mg C m-2 d-1, is accompanied by comparatively small methane release into the atmosphere, typically 7.2 mg C m-2 d-1. The originally flooded standing stock is that of the Brazilian cerrado vegetation with a typical standing stock of 75 t of green biomass per hectare which corresponds to 1.875 kg C m-2. Upon flooding, the softer tissues of the standing stock decompose within about 3 years and its carbon is emitted as gas or then leached as humic substance. During that initial period methane release into the atmosphere is typically between 10 and 100 mg CH4 m-2d-1. The harder parts decay slower, but disappear in about 40 years. But from the start, as the original standing carbon stock gradually disappears, decomposing detritus builds up new sediment carbon at 137 mg C m-2 d-1 as if it were replacing the original standing stock. Thus, in about 38 years there accumulates as much permanent carbon in the sediment as there was in the original live standing stock. This accumulated carbon continues to grow steadily and doubles over the next 38 years. If, in comparison, the performance of the original standing vegetation is considered, it does not continually grow like the accumulated sediment carbon. It being a mature forest with a fixed standing stock mass, from it as much carbon is emitted in decomposition as is fixed by photosynthesis. Not so in an anoxic reservoir bottom, which acts as a continuous carbon sink.

A controversial point is how the emitted methane, here 7.2 mg C m-2 d-1, should be considered . Should it be multiplied by some factor and subtracted from the sedimented carbon? We argue that over a horizon of many centuries, which we are considering here, emitted methane behaves like emitted CO_2, and should not be subtracted from carbon

Thermal and Hydrological Impacts of Increased Wind Speed on Lake Superior

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Several aspects of meteorological forcing over Lake Superior have been changing over the last several decades; the impacts of decreased ice cover have been explored
(foremost among these is an earlier spring overturn and subsequently higher summer surface water temperatures); the impact of increased wind speeds, also observed, have not. Increased wind speed may itself be a consequence of higher surface temperatures which reduces the stability of the marine boundary layer. In this paper, we explore the impact of increased wind speeds on mixed layer depth and water level. The increase in wind speed may be leading to deeper mixed layers and more rapid exchange of heat with the atmosphere. Increased wind speed, along with trends towards decreased ice cover and increased water temperatures are likely to lead to greater evaporative rates, which is consistent with an observed long-term trend towards lower water levels in Lake Superior.

Will Zebra Mussels Alter the Response of Ecosystems to Increasing DOM Supply

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The ability of zebra mussels to use dissolved organic matter (DOM) as an energetic subsidy can allow these organisms to cause persistent declines in phytoplankton biomass without starving. Consequently, the presence or absence of zebra mussels in a lake or river may have a profound effect on the response of these ecosystems to increases in the supply of DOM from the terrestrial environment. In this study, we re-analyze physiological and water column data from the Hudson River to assess the role that terrestrial DOM subsidies have played in the reduction of algal biomass by zebra mussels. We show that without this subsidy, phytoplankton biomass would be approximately 2-fold higher than it is today and blooms would be more frequent. Using extant data on the zebra mussel population, we also assess whether increases in DOM within the Hudson may have amplified the effects of zebra mussels over time as predicted. Finally, we use a more general population model to address the conditions under which DOM subsidies are most likely to enhance the effect of zebra mussels.

Constraining Precipitation Variation in the Tropical Andes Using Lacustrine Sedimentary Records

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The history of Holocene precipitation in tropical South America, including the roles of Pacific and Atlantic SSTs in forcing regional precipitation, is mostly unknown. In this study diatom abundances, carbonate chemistry, and stable oxygen isotopic ratios of carbonate sediments are used to develop a new methodology for calculating mean annual precipitation. Precipitation is reconstructed from a high-resolution (sub-decadal) lacustrine sediment record in the tropical Andes of Peru that spans the last ~6700 yr. The precipitation time series reveals significant wet/dry alternations with an average frequency of ~240 years and an average duration of ~100 years. The largest amplitude events were +15% departures from the prevailing mean annual precipitation. These large sustained changes of precipitation would have had a major impact on the biota and early human occupants of the region. The Holocene turned wetter 5000 cal yr BP indicating a long-term control of regional summertime insolation on monsoonal precipitation. Centennial variation of precipitation appears to correlate with Holocene Bond cycles, suggesting a major influence of North Atlantic SST on precipitation in the tropical Andes.

The Likely Effects of Climate Change on Lakes in the Endorheic Basins of Africa Through 2100

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The inherent sensitivity of lakes in endorheic basins to alterations in temperature and precipitation patterns allows them to serve as sentinels of climate change. Some of the world's most important endorheic lake regions are in Africa where capacity to adapt to climate change is low and where rapidly increasing populations are already putting pressure on many lakes through upstream water abstractions. The results of two scenarios from three coupled atmosphere-ocean global climate models downscaled to 30 arc second resolution (WORLDCLIM) provide inputs for a GIS-based hydrologic model to predict changes in water balance of lakes in the endorheic basins of Africa. Overall, most African endorheic lakes see increased evaporation and decreased precipitation leading to lower water levels, higher salinities and in some cases complete desiccation. Higher salinities as well as greater fluctuations in salinities due to increased climatic variability will likely lead to a loss of biodiversity and capacity to support migratory waterfowl in many lakes. However, for the East African Rift Valley, a predicted increase in precipitation may lead to some currently dry areas filling to become semi-permanent lakes.

Lakes as Nutrient Sinks: Does Climate Mediate Nitrogen and Phosphorus Retention?

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Lakes are important sites of nitrogen and phosphorus retention; however, long-term changes in processing within catchments and lakes resulting from acidification and climate change may affect the ability of lakes to retain nutrients. For example, runoff mediates rates of nutrient and carbon delivery, and in-lake processing is affected by factors such as residence time, onset of stratification, and epilimnetic temperature. Using approximately 30-years of lake chemistry, input and output data from 8 study lakes in central (Dorset) and northwestern Ontario (Experimental Lakes Area), we assess whether nitrogen and phosphorus retention, concentrations and speciation vary over time, whether retention shows climate, fire or acidification-associated controls, and whether retention is synchronous among elements (carbon, nitrogen and phosphorus). Our analyses indicate that nitrate retention is temporally coherent among Dorset lakes, but that it is declining. We also discuss the marked decrease in total phosphorus concentrations in these study lakes.

Higher Air Temperatures Affecting the Probability for Meromixis

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Meromixis controls cycling of dissolved matter and recycling of matter from sediments. Hence it strongly impacts the biocenosis of lakes. During thermal stratification in summer, meromictic lakes typically show three separate layers: an episodically circulated epilimnion, a colder hypolimnion below, and a chemically different monimolimnion at the deepest locations of the lake bed. Density stability is maintained by a thermal gradient between epilimnion and hypolimnion and by differences of dissolved substances between hypolimnion and monimolimnion generally against a de-stabilizing temperature gradient. Rising air temperatures will also manifest in changing temperatures in these layers. The layers, however, will not be equally impacted. Hypolimnion temperatures for example are controlled by winter temperatures, while groundwater and monimolimnion are also susceptible to changing temperatures in summer. In consequence, temperature differences between layers will change and so will density differences contributed to them. Trends will differ between various climates and latitudes. Conclusions will be drawn, where meromixis will become more (less) probable, if temperatures continue to rise.

Climatic Regulation of Nitrogen Influx to Lakes in Alpine Catchments

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Stable isotopes of N were analyzed in modern lake sediments across treeline, dissolved organic matter (DOM), and sediment cores spanning the past 12,000 yr to test the hypothesis that long-term (10-1000 yr) changes in the N content of lakes arise mainly from climatic variability that regulates the influx of terrestrial DOM into lakes. Because lake sediments integrate N isotope signals from atmospheric, terrestrial and aquatic sources, we hypothesized that N influx would be greatest when catchments were vegetated and DOM-N comprises the highest proportion of N influx. Our analysis revealed that DOM exhibited depleted N signatures (0 to 1 o/oo), that alpine lakes were enriched (4 o/oo) relative to subalpine sites (0 o/oo), and that climatic cooling during the Holocene twice reduced sedimentary N isotopic signatures from 4.5 o/oo (alpine) to 1 o/oo (subalpine). Based on these analyses, we predict that future climate warming will first reduce N influx because of loss of snowpack, but that on centennial scale, global warming will increase N influx and lake production by increasing production and influx of DOM from high-elevation soils.

Climate and CO2-Saturation Throughout the Holocene in the Pyrenean Lakes

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Diatom remains are excellent for reconstructing either pH or alkalinity from lake sediment records. These two variables may be seen as the same factor at paleolimnological scales. However, any discrepancy between the two variables, if meaningful, would indicate changes in CO_2-saturation. Using a training set of 115 lakes from the Pyrenees, we found that both alkalinity and pH were significant ($p<0.001$) in explaining diatom composition even if the influence of the other variable was removed, as assessed by partial canonical correspondence analyses (CCA) and Monte-Carlo tests. Therefore, we developed transfer functions for pH and alkalinity (both jack-knifed $R2 > 0.8$) and applied them to high-resolution Holocene diatom records from two Pyrenean lakes of contrasting size. The two records showed similar patterns of change throughout the Holocene. Alkalinity was higher during the so-called climatic optimum at mid-Holocene, indicating higher rock weathering at warmer periods. Interestingly, discrepancies between pH and alkalinity patterns were similar for both lakes. Using pollen (summer/fall) and chrysophyte cysts (winter/spring) climate reconstructions, it was found that CO_2-saturation largely depended on ice-cover length.

Climate Change in the Tahoe Basin: Impacts and Drivers

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The warming of Lake Tahoe is linked primarily to trends in air temperature. The purpose of this study was to analyze the long-term trends in climate and hydrology that may affect the lake. Using the Mann-Kendall test, I analyzed trends in 1) average monthly maximum and minimum daily air temperature (Tmax and Tmin) at 5 stations in the Truckee-Tahoe region; 2) the timing of snowmelt for 5 basin streams; 3) the fraction of annual precipitation as snow, and by OLS regression, related these variables to the Pacific Decadal Oscillation (PDO). The results indicate 1) significant shifts in snowmelt timing and the snow:rain ratio; 2) a higher than expected warming trend in Tmin at Tahoe City, and a summer cooling trend in Tmax on the Lake's windward side; 3) a minor but significant role for the PDO. The hydrologic changes may interact with the lake's increasing thermal stability to impair water clarity; the temperature trends may indicate the operation of feedbacks in the lake-mesoclimate system. The latter would suggest the need for a coupled lake-atmosphere basin-scale climate model.

Interannual Lake Temperature Trends as Indicators for Recent Climatic Change in Peninsular Florida

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Data from 47 lakes in the Florida peninsula, collected between 1968 and 2004, were examined to evaluate influence of geographic location, surface area, organic color and trophic state on surface water temperatures, and to quantify interdecadal temperature trends. Only latitude exerted statistically significant control over mean annual surface water temperature and mean annual temperature range. Seasonally, latitudinal control was most pronounced during winter and broke down consistently during summer, matching air temperature patterns. Based on these results, it is suggested that lake temperature records can be utilized for study of regional climate.

Statistical comparison of ten-year temperature means provided no evidence for long-term change in thermal characteristics during summers, whereas winters displayed a complex pattern of interdecadal variability marked by rapid warming of 2.1 ± 1.0ºC (±SD) between intervals 1 (1975-1984) and 2 (1985-1994), followed by moderate cooling of 1.0 ± 0.8ºC between intervals 2 and 3 (1995-2004). Since the net trajectory indicates warming, and climate change is expected to maintain that trend, range expansion of subtropical and tropical species north of historical habitats is expected and may already be occurring.

Ecosystem Thresholds in Lakes in Response to Climate Change

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Ecosystems can abruptly shift from one state to another contrasting state producing changes in dominance of organisms and overall ecosystem behavior. Regime shifts in aquatic ecosystems often occur after reaching an ecological threshold as driven by anthropogenic nutrient enrichment and/or climate forcing. We are bringing together concepts generated in contemporary ecological studies to test hypotheses using paleoecological data to study sudden mode shifts and ecological reorganizations in lakes. We are investigating how lakes respond to climate, during periods of both cooling and warming, and identification of thresholds or tipping points at which regime shifts occur through meta-analysis of existing records. We are examining for ecological reorganizations and regime shifts that are recorded in lake sediments during the Medieval Warm Period and Little Ice Age climate shifts and during the transient but prominent climatic perturbation around 8200 y BP. This knowledge is fundamental to predict future changes in aquatic systems, particularly in response to climate change.

Effects of Increased Dissolved Organic Matter on Zooplankton Vertical Distribution in a UV-Transparent Lake: Results From Large-Scale Mesocosms

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Climate change may increase dissolved organic matter (DOM) inputs to some lakes, which may influence UV radiation penetration and food web responses, subsequently altering zooplankton distribution. We used mesocosms to test the hypothesis that DOM additions to a transparent lake alter zooplankton day- and nighttime vertical distribution. DOM was added in two spikes over time to attain three different concentrations in addition to the control, and zooplankton were sampled after each spike. We expected that the daytime distribution of Daphnia and diaptomids would be shallower with increasing DOM concentration, but instead we observed that DOM affected their distribution more strongly at night. Both taxa were shallower in the control and deeper or more evenly distributed in the DOM treatments at night. Nauplii were shallower with decreasing DOM during both times of day. These results indicate that although DOM reduces UV penetration, it may not alter the daytime vertical distribution of UV- or light-sensitive migrants. The role of DOM on vertical food resource distribution should be examined in lakes where DOM inputs may be altered by climate change.

Prairie Pothole Lakes in North America: Indicators of the Past and Predictors of the Future Carbon Storage in Shallow Lakes

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Small aquatic systems play a disproportionately high role in storing organic carbon in aquatic systems. The mechanisms that drive carbon sequestration in wetlands are not well understood, and the degree to which wetlands and shallow lakes can compensate for anthropogenic CO2 emissions via carbon sequestration is unknown. Recent overviews of the importance of freshwater systems in carbon sequestration suggest both that wetlands might play an important role but also that we do not know much about the processes involved. In order to accurately estimate the impact of shallow lakes on moderating warming effects on a global scale, the process and extent of carbon sequestration in shallow lakes needs to be evaluated and quantified. We have been examining both the current and past (ca. 200 years before present) behavior of wetlands in North America's Prairie Pothole Region. Our results indicate that (a) these systems are important regional components to the central US carbon cycle both presently and in the recent past, (b) that the dominant type of plant (macrophyte vs. phytoplankton) has little effect on carbon fluxes into wetlands.

Lakes as Sensors of Landscape and Climate Change: A Global Sensor Web

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The global decline in freshwater quantity and quality has inspired the formation of international organizations that study lakes as indicators of change at local, regional, and global scales. Associated with these organizations are automated measurements of meteorological, hydrological, and limnological variables that have lead to explosive growth in data quantity and challenges in data assimilation and interpretation. When combined into a network of sites, the analytical demands compound, and the approaches envisioned for one lake do not necessarily scale well to hundreds or thousands of lakes. What is needed is a new intellectual paradigm for understanding how the properties of the great diversity of individual lakes can be generalized to capture the aggregate characteristics as we move from local to global scales. Here we introduce the “Sensor Web of Lakes” paradigm as an extension and modification of the “lakes as sentinels” view. A lake as a sensor has signal output with pattern at multiple space and time scales related to external driving forces mediated by the lake’s fundamental biotic and abiotic structure, generating a new set of potential meta-characteristics.

Nutrient Loading and Climate Warming: two Synergetic Drivers of Freshwater Algal Dynamics?

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Changes in the phenology and the distribution of individual species are evidence of the impact of climate change on biological systems. However, the observed responses of individual plant and animal species are just the starting point of tackling the ecological complexity of ecosystem responses to climate change. Other drivers of ecosystem functioning, such as habitat fragmentation, eutrophication and pollution may act in concert with climate change. Non-additive impacts of these multiple ‘stressors’ make it difficult to predict effects based on single-stressor studies. Our analysis of the full-ecosystem model PCLake suggested that nutrient loading and climate warming may have non-additive synergistic effects on lake systems. By exposing natural plankton communities to different spring warming scenarios and nutrient loading scenarios in a full-factorial experimental microcosm design, we checked whether climate warming and nutrient loading act as synergistic or antagonistic drivers of freshwater plankton community dynamics. The outcome of these experiments indicates that nutrient loading and climate warming may act as synergistic drivers of algal dynamics, both impacting the carrying capacity of the algal community.

Synergetic Effects of UV Radiation and Temperature in Cold-Adapted Calanoid Copepods From Patagonia (Argentina): Bioaccumulation of Photoprotective Compounds and Mortality Trends

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Climate change is likely to impact aquatic ecosystems in the Patagonia region of Southern South America through different mechanisms: (i) direct increase in UV due to ozone depletion, (ii) direct effect on water temperature and (iii) indirect effects of temperature on tolerance of organisms to UV and changes in the radiation environment mediated by changes in DOC levels. The identification of biological processes influenced by UV exposure and temperature in predictable ways will improve our appreciation of their combined effects on freshwaters. In the copepod Boeckella antiqua, the accumulation of photoprotective compounds (MAAs and carotenoids) could be dissected out into uptake and elimination processes, both of which are strongly and predictable influenced by UV and temperature. However, Boeckella antiqua is restricted to a few sites in Northwestern Patagonia. Here, we extend the results to B. gracilis, which occurs along a broad latitudinal gradient from 6º N to 49º S. Analyses of mortality trends suggest that increases in temperature will translate into additional photo-toxicity stress in Boeckella species, even under a stable UV scenario.

Dissolved Organic Matter: Long-term Changes in Fluxes, Concentrations and Retention

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In most Boreal lakes, DOM is largely of allochthonous origin. Microbial respiration and photodegradation are sinks for DOM, with the latter process being pH-dependent; photodegradation rate is much faster at lower pH. Sedimentation is also a major sink in most lakes, although photochemical reactions may play a role in this pathway as well. DOM levels in streams are increasing in much of northern Europe and some parts of North America; however, the reasons for this are unclear but have been linked to climate change, land use change, and changes in acid deposition. In other regions, monotonic trends are not observed; for example, in lakes in Ontario there is a synchronous pattern that is inversely correlated with radiation levels. We examine long-term (25 year) changes in DOM fluxes from catchments, concentrations and retention in 7 lakes and their catchments to evaluate the role of climate in mediating these changes.

Detailed Estimation of the C Accumulation Fluxes at Las Tablas de Daimiel National Park (Spain) for the Last 1000 Years and how are Influenced by Climate and Anthropogenic Activities

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Lakes, reservoirs and wetlands have a large importance in the Global Carbon Cycle; because they have a great capacity to sequester C for a long time. However it is difficult to know exactly the amount of C that those ecosystems can store now and in the past. Specially difficult are the estimations for wetlands (the approximations in the literature have errors of the 100%) because are a very heterogeneous ecosystems and have a high terrestrial influence. In this work we present a detailed estimation of the C accumulation fluxes at Las Tablas de Daimiel National Park (Mediterranean fluvial wetland located in central Spain) for the last 1000 years. The estimation is based in 70 cores, 15 of them (keys cores) have been selected for geochemical, isotopic, mineralogical, sedimentological, physical, pollen analyses and dating, the others have been used mainly in the correlation. We found a high variability in the annual accumulation fluxes (290-0, 1 g/m2/year for OC and 120-0 g/m2/year for IC) caused by natural (climate) and anthropogenic (draining, water overexploitation…) changes in the flooded surface of the wetland.

Climate Control of Spring Clear-Water Phase Development Through the Transfer of Energy and Mass to Lakes

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We sought to distinguish between pathways by which climate affects lake structure and function by using the clear-water phase (CWP) as a model system. We compared decade-long time series of water transparency, algal abundance and zooplankton density to identify the CWP in six polymictic lakes of the Northern Great Plains and to determine how energy and mass transfer interact in regulating lake structure. Analysis of ecosystem synchrony revealed that CWP timing was highly variable among lakes, but could be predicted from the rate of energy transfer from the atmosphere (r2 = 0.984, p = 0.0001). CWP occurred when water overlying the sediments reached 16oC and

Daphnia populations reached sufficient density to clear the water column of diatoms. However, during years of elevated winter NAO indices, increased river discharge reduced the effect of heat influx on CWP timing and intensity. Taken together, these analyses reveal that differences in CWP characteristics among lakes are due to site-specific variation in the rate of energy accumulation, whereas inter-annual variability in mass transfer can obscure this relationship within individual lakes and among years.

Using Paleolimnological Records to Separate Impacts of Management, Land-use, and Climate in US National Park Lakes

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The US National Park Service protects large relatively undisturbed ecosystems that can serve as ecological sentinels of climate change. Resource management in the Great Lakes Network (GLKN) parks of Voyageurs, Grand Portage, Isle Royale, Apostle Islands, Pictured Rocks, Sleeping Bear, and Indiana Dunes is heavily focused on aquatic systems including lakes. We have used dated sediment cores from a cross-section of these lakes to reconstruct limnological history from diatom remains and various geochemical indicators. As might be expected, broad scale land-use changes (logging, land clearance, damming) associated with Euro-American settlement have been major drivers of environmental change in GLKN lakes. However, most of the sediment records across this broad geographical area also show synchronous post-1970s ecological shifts while under a "preserve unimpaired" management policy where land-use changes have been minimal. These shifts are correlated in part with signals of climate change, although the exact mechanisms are currently unclear and other large-scale drivers (e.g. atmospheric deposition) must also be considered.

Simulations of Climate Effects on Water Temperature, Dissolved Oxygen, Ice/Snow Covers, and Fish Habitat in Lakes of the Contiguous USA under Past and Future Climate Scenarios

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Daily water temperature and dissolved oxygen (DO) profiles, and ice/snow covers on lakes were simulated for 27 types of lakes at 209 locations in the contiguous USA under observed past (1961-1979) and projected 2xCO2 climate conditions (from the Canadian Climate Centre General Circulation Model). A verified, process-oriented, unsteady and one-dimensional (vertical) year-round lake water quality model was developed and applied for the temperature and DO simulations, which were run in daily time steps over 19 years. Habitats for cold-, cool- and warm-water fish in small lakes were therefore determined from simulated daily water temperature and DO profiles. The 2xCO2 climate scenario is projected to increase lake surface temperatures by up to 5.2oC, to increase the duration of seasonal summer stratification by up to 66 days, and to shorten ice cover periods by up to 90 days. Nine thermal/DO fish habitat parameters were developed, and simulated habitats agree well with fish observations. Summerkill under the projected climate scenario is a projected significant negative impact on cool-water fish in southern lakes of the contiguous USA, where suitable habitat existed under past conditions.

Climatic and Chemical Regulation of CO2 Flux in Hardwater Prairie Lakes

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Net ecosystem production regulates CO2 fluxes in softwater lakes, however, little is known of hardwater ecosystems in which alkalinity and pH may control carbon (C) storage. Annual carbon flux was measured for 14-yr in six hardwater lakes within a 52,000 km2 catchment. Overall, changes in pCO2 levels ($r = 0.8$) and CO2 flux ($r = 0.5$) were synchronous among lakes due to coherent changes in pH, total inorganic carbon content, and temperature. In most years, all lakes exhibited low pCO2 and high CO2 influx, while CO2 was lost from all basins during 1999-2000. These trends were uncorrelated with ecosystem production and respiration ($r < 0.2$), but instead were controlled by

inorganic C influx during winter that reset spring pH and chemical enhancement of CO_2 uptake during summer. Comparison with an additional 21 lakes in a
separate 100,000 km^2 area suggests that chemical control of CO_2 flux is also common among saline lakes. Because these lakes account for 50% of surface waters, improved understanding of the controls of pH is essential to evaluate the role of lakes in global carbon budgets.

Organic Matter Burial in Arctic Lake Sediments: The Effect of Temperature, Oxygen Availability, and Autochthony

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Lakes sediments may represent a significant global carbon sink; however the factors affecting carbon burial in lakes are poorly understood. We evaluated the impact of temperature, oxygen availability, and organic matter source on sediment organic matter mineralization in three shallow oligotrophic lakes in the Alaskan Arctic. The lakes have organic rich surface sediments (25.3 to 53.0 %) and high burial efficiency (60 and 70 % of surface organic matter retained to 10 cm). Organic matter mineralization was measured as the dark sediment oxygen demand (SOD) of intact cores. SOD varied between 8.4 and 20.6 mmol O_2 m^{-2} d^{-1} with 64 % of the variation explained by oxygen availability and temperature. The lake with the highest SOD independent of oxygen availability and temperature had more autochthonous sediments based on Chlorin Index and $SUVA_{254}$. Our results show that organic matter burial in these lakes is regulated by temperature, oxygen availability, and organic matter source. The Arctic is experiencing dramatic alterations from climate change. Understanding factors affecting sediment carbon burial in arctic lakes will clarify their future role in global carbon cycling.

Modeling the Differential Effect of Climate Change on Monomictic Lake Ecosystems in Contrasting Climatic Regions: Southern Temperate (N.Z.) vs Sub-Tropical (Israel)

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Climate change (CC) will increasingly impact aquatic ecosystems in the future. While the likely impact of CC on physical aspects such as temperature and stratification are better understood, it is not clear what the potential impact will be on ecosystem functioning. The change in ecosystem functioning will most likely vary between lake mixing type (e.g. monomictic, polymictic), between climatic regions and with trophic complexity. To date no attempt has been made to compare the impact of CC on lake ecosystems in different climatic regions. To address this we applied the lake ecosystem model DYRESM-CAEDYM to examine responses in two monomictic lakes in different climatic regions; Lake Rotoiti in New Zealand and Lake Kinneret in Israel. Forcing data for the simulations included meteorological data extracted from global and regional climate model outputs, and current day inflows and withdrawal characteristics. We compared the impact of the predicted CC on functional ecosystem variables and key biogeochemical fluxes in the two lake ecosystems.

Lake Tahoe: Five Decades of Change and the World Water Crisis

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Aquatic ecosystem integrity is now threatened on a global scale. Declining water quality and quantity is becoming one of the most important environmental problems faced today and is closely linked with global warming and resulting climatic change. China and India’s large populations have the most serious water problems. Africa and the desert nations follow. Protection of lakes and streams from pollution and possible terrorist attack are of increasingly important. The value to our planet of lake and river waters can not be exaggerated. The half century of Lake Tahoe data evidences the gradual but relentless loss of transparency as algal growth and fine particulates cloud the water column and both exotic weed and fish introductions further threaten the lake. Like many of the world’s lakes it has significantly warmed over the last two decades. Long-term data collection and analysis have been important for better managing Tahoe and its air and watershed. Regulatory policy decisions worldwide are unfortunately often based on scanty or poorly interpreted data. Aquatic scientists and engineers with more effective public education must develop management strategies to meet this growing global crisis.

Climate Extremes Alter Northern Lake Food Webs

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Global warming is amplifying the frequency of extreme climate events, thereby resulting in pronounced fluctuations in surface water temperatures and terrigenic inputs into lakes. For example, severe droughts reduce terrigenic runoff into boreal lakes, causing them to become more chemically dilute and sensitive to warming events. Based on 32 years (1970 – 2001) of meteorological and limnological data from the Experimental Lakes Areas (ELA) in Canada, we discovered that total zooplankton abundance was suppressed, while phytoplankton biomass was significantly elevated during hot and dry summers. Therefore, we hypothesized that mid-summer heating events worsen the negative effect of reduced terrigenic input on zooplankton, releasing phytoplankton from grazing. The hypothesis was tested using an in situ two-factor (three temperature levels x three terrigenic levels) fishless mesocosm experiment at the ELA. Our hypothesis was not supported because warming instead amplified the positive effect of drought-like conditions on total zooplankton biomass, while suppressing total phytoplankton abundance. These scale-dependent differences of planktonic responses to whole-lake and mesocosm-based extreme climate scenarios highlight the potential importance of mediating factors, such as fish predation, lake phenology, and habitat heterogeneity.

Influence of Changing Climate on Subtropical Reservoirs

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Texas has a strong east-to-west gradient of decreasing precipitation ranging from humid to arid subtropical. Reservoir volume accounts for over 50% of the available surface water, and is an extremely valuable resource. Three aspects of projected future climate change, including rising air temperature, increasing variability and intensity of storm events, and a changing runoff, all have important implications for these reservoir ecosystems, the larger river ecosystem they are part of, and the society that depends on them. With data spanning over 40 years in some of these reservoirs, a response to future trends can be predicted. The hypolimnia of deep storage reservoirs are most sensitive to warming through increased rates of flowthrough during wet years, leading to a doubling of metabolism, harsher redox conditions and internal nutrient loading. Some of these reservoirs can be pushed over a trophic threshold during these years, from which they may not return. In shallower run-of-river reservoirs, reservoirs which stratify during drier years (and being much more eutrophic) often have no seasonal stratification during wet years and are oligotrophic.

Long-term Warming and Deepening Summer Phytoplankton Distribution in Lake Baikal, Siberia

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Vertical stratification of lakes can be strongly reinforced by long-term warming, but concurrent changes in wind dynamics also have a critical impact on stratification patterns. Surface waters in the world's largest freshwater lake - Lake Baikal in Siberia - are warming at an average rate of 2.01oC century-1, with more dramatic warming in the summer (3.78oC century-1). Available long-term temperature data are not sufficiently fine scaled to resolve stratification patterns. However, long-term vertical phytoplankton distributions suggest that the depth of the stratum in which algae are mixed has increased at times of unstable stratification in summer. Only August reliably stratifies in Lake Baikal, and general patterns in phytoplankton depth distribution do not suggest an altered epilimnion during this stable stratification. In contrast, during the summer months with historically unstable stratification, the mixing depth for phytoplankton appears to have increased well beyond the photic zone (e.g. 250 m), suggesting increased wind mixing. Greater wind influence may result from increasing land-water temperature differences that strengthen local winds, larger scale storm patterns, or both.

Lakes as Sensors of OC Perturbations in the Landscape

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Lakes are hot-spots in the landscape for carbon cycling, acting as both storage and mineralization sites for terrigenous organic carbon (OC). Small lakes may be particularly well suited to sense landscape perturbations because they tend to have high OC loads relative to their areas and short hydrologic residence times. Challenges in using lakes to sense landscape perturbations derive from multiple factors: difficulty in estimating base loads; uncertainty in how OC pulses are manifested in limnological response variables, such as thermal and light regimes, ecosystem respiration, and CO2 flux to the atmosphere; difficulty in detecting pulse-driven signals in limnological variables with high noise levels; lack of scaling laws for these factors over important lake gradients. Here we use a one-dimensional physical-chemical-biological model to simulate how lakes of different size, hydrology, and trophic status respond to perturbations in OC load. We study how uncertainty in predicting limnological variables, driven by weather patterns and influenced by intrinsic lake characteristics, affects our ability to detect OC pulses from the landscape.

Nitrogen Deposition, Catchment Carbon Export and Climate as Determinants of Lake Stoichiometry

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These results are based on a survey of nearly 1000 Norwegian lakes in pristine catchments. By using data for nitrogen deposition, climatic variables and GIS-data for a range of catchment-specific properties, the effect of these variables on elemental ratios between carbon (C), nitrogen (N), phosphorus (P) and silicate (Si) in downstream lakes was assessed. The study covered a wide range of anthrophogenic N-deposition from south to north (max: 2 g m-2 yr-1, min: 0.1 g m-2 yr-1) as well as highly variable climate and catchment and lake properties. Inorganic N in lakes was positively correlated with N-deposition, while organic N was closely associated with allochthonous DOC. The ratio of NO3: total N as well as NO3: total P and NO3:SiO2 showed a tremendous variability and were largely governed by N-deposition, hydrology and catchment inputs of DOC. The data allow for robust predictions of climate induced effects on organic and inorganic nutrient and nutrient ratios in lakes related to catchment changes in hydrology, N-deposition and terrestrial production.

Measures and Changes in an Arctic Lake in Alaska: Chemical Changes as Indicators of Climate Change in a Sentinel Lake

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Climate-linked changes in Arctic lakes are obvious at the environmental extremes. In the high Arctic, ice-covered lakes now have open water in the summer; in the low Arctic, permafrost thawing causes slumping of soils into lakes. But for lakes in the middle of this range, what are the indicators of climate change? A 32-year record at Toolik Lake (69oN), Alaska, shows that lake alkalinity concentration has doubled. Temperatures 20m into the permafrost have increased >0.5oC and air temperatures even more, albeit mostly in the winter. Despite the warming, permafrost at this depth is still cold (~ -4oC) and there is no measurable basin-wide thawing. The frequency of summer storms appears to have increased, but indicators of lake processes show no strong trends, including ice-cover duration, water temperature, nutrients, algal productivity, and zooplankton and fish species. However, strontium isotope ratios of streamwater entering Toolik have changed to reflect isotope ratios found in deeper soils. Thus, these chemical changes are likely caused by increased weathering of mineral soils as small amounts of thawing of permafrost occur, perhaps beneath lakes and streams.

Quantifying Limnological Change in the Anthropocene: A Comparison of High-Altitude and High-Latitude Ecosystems

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Alpine and arctic lakes are sentinel ecosystems with respect to climate-change impacts, owing to the combination of low temperatures, nival hydrological regimes, and simplified trophic structures. Here we synthesize 52 diatom-based paleolimnological records from North America and west Greenland, including alpine (n=15) and arctic (n=20) ecosystems, as well as a range of boreal-montane sites (n=17) as 'controls'. For all of these sites, diatom compositional turnover (β-diversity) was quantified over the last ~450 years. For both arctic and alpine lakes, β -diversity during the 20th century is significantly greater than the previous 350 years. Species turnover increases with both latitude north and altitude. We explore whether the amplitude of recent biological change correlates to a range of limnological variables (lake and catchment area, maximum depth, pH, conductivity, [NO3-], modeled atmospheric NO3- deposition, summer and winter air temperatures). No significant linear relationships are apparent between β -diversity and any one of these parameters, suggesting that the ecological responses are complex and potentially synergistic. A multivariate consideration of available environmental variables reveals that climate and N deposition are acting synergistically and together exert a dominant influence on diatom assemblage turnover. Regional temperature increases during the 20th century correspond to the latitudinal trend of diatom β -diversity in arctic lakes, whereas the southward increase of anthropogenic N deposition suggests that biogeochemical impacts are most pronounced in mid-latitude alpine lakes. We predict that these lakes will continue to shift towards new ecological states in the Anthropocene, as these two dominant forcings begin to intersect geographically.

Contrasting Development of Cyanobacteria Blooms During two Summer Heat Waves

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The risk of cyanobacteria blooms is expected to rise with climate warming. In this study, we tried to explain the contrasting development of cyanobacteria in a shallow, eutrophic lake during two summer heat waves of 2003 and 2006. Multivariate autoregressive models were fit to a long-term data set (1979-2007) to identify important abiotic factors and interaction pathways among the major plankton groups. The summer of 2003 was compared to 2006 regarding the identified drivers of cyanobacteria growth. This comparison revealed extremely high abundances of some zooplankton groups (mainly cyclopoid copepods and Diaphanosoma sp.) during the summer of 2003, which most likely have suppressed the inocula of cyanobacteria. In contrast, the summer of 2006 was characterized by a low abundance of zooplankton (especially few daphnids) and an extremely strong thermal stratification, which provided ideal conditions for cyanobacteria. We hypothesized that the observed differences stem from different seasonal warming patterns during 2003 (hot June) and 2006 (hot July). Thus, considering the specific timing of heat events is crucial when trying to anticipate the risk of cyanobacteria blooms under future climate warming.

Climate Change and Phytoplankton Community Structure in Lake Baikal, Siberia

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During the past 60-100 years, air temperature in the Lake Baikal region rose twice as fast as the global average; surface waters (top 25-m) of L. Baikal warmed significantly; and, the ice-free season lengthened by 18 days. Endemic diatoms, which often dominate the spring phytoplankton bloom under the ice, may be affected adversely by climatically induced changes in ice dynamics. In contrast, autotrophic picoplankton (APP), major constituents of the summer bloom, should increase in response to warmer water temperatures and enhanced stratification. We tested these expected trends using phytoplankton abundance during 1974-1999. Contrary to expectations, abundance of under-ice diatoms and summer APP did not change, possibly because of compensatory increases in abundance of cosmopolitan diatoms and grazing of APP, respectively. However, cryptomonad abundance increased

significantly during spring and summer while abundance of chrysophytes and large (> 2 μm) cyanobacteria did so only during summer. Abundance of these taxa correlated positively with warmer water temperatures according to multivariate autoregressive modeling. These results demonstrate the challenges in predicting effects of climate change on phytoplankton community structure.

Top-Down and Bottom-Up Control Strongly Affected by Global Warming in North Temperate Lakes

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Based on data from 250 Danish lakes and 800 lake-years we conducted for multiple regression analyses relating biological variables on a monthly basis to total phosphorus, total nitrogen, mean depth and water temperature. We found clear evidence of strong effect of water temperature on both biomass and not least phytoplankton composition (analysed at the class level) as well as on zooplankton – not least during summer. Total phytoplankton, cyanobacteria, not least non-N-fixing forms and dinophytes were strongly positively linked to temperature while diatoms were strongly negatively related to temperature. Besides, the changes in zooplankton suggest a major increase in predation with warming, as size of cladocerans and copepods and the cladoceran:phytoplankton ratio decreases markedly with increasing temperature. The latter is supported by fish investigations, though based on a much smaller dataset. Our results give evidence for a weakening of grazer control with climate warming and higher risk of cyanobacteria dominance. The nutrient targets for obtaining clearwater conditions is thus on the move downwards at present in north temperate lakes.

Climate Change Impacts on Lake Stratification – A Large Scale Simulation Approach

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Lake stratification is to a large extend determined by regional climatic conditions. Changes in climate patterns like increasing air temperature will lead to a shift in lake characteristics thus changing the physical basis for live in the aquatic system. Using numerical simulations with a k-epsilon turbulence model we simulate the seasonal hydrodynamics of lakes in Europe. To account for hydrodynamical differences due to lake morphometry and trophic state, we use several model lakes differing in depth and absorption coefficients, respectively. The model lakes are forced by meteorological data given as gridded fields over Europe for current climate condition as well as for future climate scenarios. This results in several tens of thousands simulations of lake temperatures and turbulent diffusivities, from which we extract cardinal events and values such as the onset of stratification, length of stratification period, thermocline depth or ice cover duration. Using the reference meteorological conditions our simulations provide predictions for differences in lake hydrodynamics and ecology, e.g. start of the algal spring bloom, length of the algal growing period, across the latitudinal, longitudinal and altitudinal gradients.

Lake Productivity and Biostructure along a Climate Gradient in Northern Sweden

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We studied the basal production by algae and bacteria and the resource use and growth of top consumers (Arctic char, Eurasian perch) in lakes along a climate gradient (subarctic-boreal) in northern Sweden. Subarctic clear water lakes were dominated by benthic production and resource use while humic boreal lakes were dominated by pelagic production and resource use. Lake productivity was negatively correlated to the amount of inorganic nutrients and coloured dissolved organic matter (CDOM) in the lake water, which relationships were attributed to the negative effect of CDOM on the light climate and consequent basal production in the benthic habitat. Thus, the loss of benthic production and resource use was not fully compensated for by an increase in pelagic production

and resource use, despite increasing nutrient input. The data suggest that climate has a major impact on the productivity and biostructure of unproductive lake ecosystems by its control of terrestrial export of organic carbon to lakes and that warming and increased input of inorganic nutrients not always result in increased lake productivity.

Shallow Lake Response to Climate Change: the Role of the Heat Storage by Sediments

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The effect of climate change on seasonal thermal structure of shallow temperate lakes is investigated. The analysis is based on 1961-2005 observational data sets from two Berlin lakes, regional climate scenarios until 2100 and a one-dimensional lake temperature model including a sediments temperature submodel.

According to the results, the heat storage by lake sediments plays a significant role in lake response to climate change and consists in shifting of the overall warming trend to the winter hypolimnion heating. In future projections, the common scenario suggests transition of the mixing regime in shallow lakes from polymictic through dimictic to warm monomictic. The distribution of the warming trend over the seasons differs significantly for different mixing regimes, especially in the hypolimnion: the gradual temperature increase, especially in summer (polymictic conditions), followed by the drop of summer temperatures with strong winter warming (dimictic conditions) and passing to the fast increase of the summer bottom temperatures (warm monomictic conditions).

The established temporal pattern of the climatic temperature variations at the water-sediments boundary affects the lake water quality by controlling the oxygen regime, the biochemical processes in sediments and the water-sediments mass exchange.

Reservoir Carbon Budgets Mediated by Land Use and Precipitation Variability

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Reservoirs often sequester large amounts of terrestrial organic carbon, and may impact regional and global carbon cycles more than lakes because of their large watersheds. However, it is unclear what percentage of incoming carbon is buried into sediments versus emitted as CO2. Our study is unique in that we examine dynamics of DIC, DOC, PIC, POC, and pCO2 in two reservoirs of contrasting watershed land use, and relate retention to climate variability (severity and frequency of storms) over two years. During storm events, both Acton (hypereutrophic, agricultural watershed) and Burr Oak (mesotrophic, forested watershed) retained much incoming POC (47%, 72%, respectively) while at low flow, there was a net export of POC. Burial rates per unit reservoir area were much higher in Acton than Burr Oak (108, 13 gC/m2/yr, respectively), indicating higher terrestrial organic carbon subsidies and within-reservoir production in Acton. In contrast, both reservoirs had similar pCO2 dynamics, being net autotrophic except in late summer when they were net heterotrophic. Reservoirs may be significant carbon sinks, but their role in this process is mediated by land use and precipitation.

A Study of the Subsurface Water Role in Water Resources of Lake Michigan: Ecological Policy, Assessment and Prediction

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The project is designed to consolidate fundamental areas of research available in field investigations and modeling of Submarine Groundwater Discharge (SGD), that are necessary for understanding, quantifying, forecasting and combating the Lake Michigan contamination process. Special attention is paid to fresh, low-brackish and polluted groundwater spreading in hydrological cycle and to the groundwater intake influence on the Lake Michigan environment. SGD and groundwater inflow quantitative assessment allows the determination of the role of groundwater in the Lake Michigan water balance, coastal zones balance and helps to characterize the distribution of fresh groundwater resources suitable for domestic water supply. This area had proven to be very sensitive to changing human activities and climate variability.

Searching for Critical Thresholds for Mid-Summer Breakdown of Thermal Stratification in Subarctic Lakes of Finnish Lapland

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The length of the mixing period and the strength of the summer thermal stratification have focal impacts on the biology of northern lakes so that marked changes in them have been proposed to lead to ecological regime shifts. From 1996, we have studied thermal features of >30 sub-arctic, clear-water lakes in Finnish Lapland using automatic mini-thermistors. Our data indicate that the development of the thermocline in moderately deep, wind-stressed lakes (8-30 m) is heavily controlled by early summer weather conditions. Year 2001 was very unusual, as the mid-summer stratification suddenly broke down even in the deepest lakes that have clearly been thermally stratified during the rest of the summers. The thermocline never developed again during the late summer pointing to the possible hysteresis behavior. Here we carry out detailed investigations of the weather characteristics that contributed to the breakdown of the stratification in the lakes and attempt to determine critical thresholds that may affect the behavior of sub-arctic lake ecosystems under future climate conditions.

Carbon Evasion/Accumulation in Randomly Selected Boreal Lakes Located Between Latitudes 60o N and 69o N

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Lakes in the boreal zone are predominantly net heterotrophic, evading both terrestrially fixed C into the atmosphere and burying organic carbon in sediments. There are 56 000 lakes larger than one hectare in Finland, covering 10% of the country's total area. Subpopulations of 177 and 122 lakes were randomly selected from the Nordic Lake Survey data base for greenhouse gas and sediment C stock studies, respectively. Land use of the surrounding catchments and water quality (4 seasons, 4 depths) were determined for each lake. These data sets demonstrate that boreal lakes are important conduits for transferring terrestrially fixed C into the atmosphere. Both CO_2 concentrations and Holocene C stock in the sediments were highest in small, shallow lakes. Lakes north from the Arctic Circle had lower nutrient concentrations and C evasion/accumulation ratio compared to the lakes in the south. Further, CO_2 evasion followed closely the precipitation pattern. Climate change scenarios predict increasing temperature and precipitation for the northern Hemisphere which can significantly contribute to biogeochemical cycles - according to Finnish data resulting in increasing eutrophication coinciding with increased CO_2 fluxes.

The Global Lakes Ecological Observatory Network: Facilitating the Coupling of Observations and Models Across a Global Gradient of Lakes

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The Global Lakes Ecological Observatory Network (GLEON; http://gleon.org <http://gleon.org/>) is an international grassroots network of ecologists, engineers, and information technology experts that use instrumented buoys on lakes worldwide to collect and analyze persistent, high-frequency observations of lake dynamics. These data, which at a minimum consist of water temperature profiles, dissolved oxygen concentration at one or more depths, and a suite of weather variables are recorded at sub-hourly frequencies. High-frequency data such as these have proven useful for testing coupled physical/biological models. GLEON is developing an information management system that will allow users to access these lake data easily and efficiently. GLEON includes participants from Asia, Europe, North America, Oceania and South America and includes lakes spanning large gradients in size, depth, trophic status, and climatic regime. This diversity of lakes lends itself to powerful comparative analyses of climate/lake interaction. As of February 2008 data from seven lakes in Wisconsin, New Hampshire, Florida, and Sweden are currently in the GLEON information management system with additional lakes scheduled to be added. GLEON can ultimately serve as a global network of sentinel lakes.

Uncertainty in the Boreal Lake Region Response to Climate Change

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Simulated global climate scenarios are routinely used as inputs to downscaling studies that attempt to forecast the response of aquatic ecosystems to climate change. But these global climate scenarios become increasingly uncertain going from global scales to regional scales. One sign of this uncertainty is that different climate models, or even moderately different tunings of the same model, can produce markedly different regional scale resposnes in temperature and precipitation. Such discrepancies are particularly problematic in the boreal lake region, because of the large climate variability of the extratropical zone. We show that simple retuning (within parameter uncertainty) of the physical parameterizations of global climate models can give very different precipitation, circulation, and surface temperature responses to climate change – all of which are relevant to aquatic systems. We will also discuss some aspects of regional simulations, for example changes to the surface radiation and UV flux, that might be used more reliably for regional scale ecosystem research.

Variations in Colored Organic Matter in Lakes Studied by Satellite Remote Sensing Across Regions and Climates

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Colored dissolved organic matter (CDOM) in lake water derives mainly from the terrestrial environment, and its concentration depends strongly on climate. CDOM is a useful proxy for the concentration of dissolved organic carbon and for the CO2 supersaturation of lake water.

Consequently, CDOM data can help to understand the role of lakes in the transfer of terrestrial carbon to the atmosphere, and in combination with other data such as runoff and the size and land use of watersheds, it can help in the quantification of how inland waters transport and transform organic matter during transit from land to sea. CDOM measurements are straightforward. However, a very high number of lakes need to be sampled to achieve regional or global overviews necessary to understand the coupling between climate and CDOM. We demonstrate that satellite remote sensing can make such large sample sizes realistic. We estimated CDOM concentrations in about 3400 lakes in Scandinavia and eastern North America using Advanced Land Imager data. Our data demonstrates regional differences in CDOM concentrations, which we discuss in terms of climatic differences.

Principal Catchment Specific Determinants for Organic Carbon in Norwegian Lakes

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During a Norwegian lake survey, the amount of total organic carbon(TOC) was measured in approximately 1000 lakes. To understand which factors influence the observed variance in TOC, we used GIS to gather catchment specific data on parameters such as precipitation, average annual temperature, catchment slope, altitude, longitude, area use, vegetation type, lake area, UV-radiation, vegetation density etc. Scores from the main axes of a principal component analysis were used to establish a simple linear TOC-model which explained 85% of the variation in the measured TOC values. The model coefficients were then used to estimate expected TOC in the around 20.000 drainage units from the Norwegian catchment classification system, covering the entire area of Norway. With estimates of specific TOC and data describing the run-off for each catchment area it was possible to estimate the total export of terrestrial organic carbon from the Norwegian mainland to the sea. Several of the variables included in the model are directly linked with climate change. Thus, this work also addresses significant feed back processes related to different climate change scenarios.

Greenhouse Gas Emission by Thermokarst Ponds: Microbial Assemblages, Dissolved Organic Matter and Other Controlling Factors

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One of the consequences of Arctic warming is the accelerated melting of permafrost, leading to formation of thermokarst ponds and mobilization of a pool of carbon that has accumulated over timescales of thousands of years. We sampled several ponds in the Canadian subarctic (55°N) and Arctic (73°N) since 2004. They are relatively productive systems with abundant and diverse microbial assemblages, with turbid subarctic ponds apparently net heterotrophic. Most ponds sampled were supersaturated in CO2 and CH4, indicative that the system acts as a source of carbon to the atmosphere. In 2007, CO2 fluxes measured with a floating chamber varied from -696 to +2280 mgC m-2 j-1 (n=27), with negative fluxes recorded in arctic ponds colonized by thick microbial mats. Dissolved CO2 and wind speed followed during 8 days in one subarctic pond indicates large variability in estimated fluxes. Newly formed ponds are likely releasing a significant quantity of carbon to the atmosphere until they drain out or are colonized by vegetation, possibly reversing fluxes. Influences by dissolved organic matter, thermal regime, transparency and microbial activity on carbon emission from these ponds are under investigation.

Paleolimnological Evidence of Modes and Mechanisms of Climate Variability and Effects on Lakes

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Analysis of the biological, geochemical and physical components of lake sediments reveals that climate alters lake structure and function by regulating the flow of energy (PAR, UVR), water, and critical dissolved elements (DOC, H+, N, P, Si), but that the relative importance of control mechanisms may vary in time and space, and interactively with human activities. In some settings, lakes exhibit bounded modes of variation in which long periods of relative stability or characteristic frequency are punctuated by rapid change across potentially irreversible thresholds. Other systems show periodic or recurrent variation associated with atmosphere-ocean linkages (ENSO, NAO, etc.) that can produce seasonal-to-decadal synchrony among lakes, particularly when climate variability is expressed though the transfer of energy. In general human activities can diminish or intensify climate effects on lakes, although anthropogenic effects appear to act mainly through the transfer of mass. Despite these generalities, challenges remain to identify the mechanisms by which multiple forcing factors interact, as well as to predict how regulatory hierarchies may vary in the future.

Climate Change and DOM Photomineralization: Implications for Lake CO2 Evasion

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The net flux of CO2 from lakes is generally attributed to the microbial respiration of allochthonous dissolved organic matter (DOM). However, photolysis of DOM also contributes to CO2 evasion. DOM can be photolyzed directly to CO2 or into smaller, labile substrates, which stimulate microbial metabolism. Climate-related shifts in forest composition will likely affect the quantity and quality of DOM entering lakes, and consequently, rates of photolysis. We examined the photodegradation of leachate derived from plants grown at ambient (360 ppm) and elevated (720 ppm) atmospheric CO2 concentrations. Rates of photolytic CO2 production were determined for sterilized leachates ranging from 5 to 100 mg L-1 dissolved organic carbon (DOC). Photolytic CO2 production was generally greater for ambient CO2 leachates compared to elevated, correlated with increased humic content. Photolytic CO2 production increased linearly with DOC concentration; however, the 5 mg L-1 treatment had the greatest rate per unit carbon. The magnitude of the photolytic CO2 flux from lakes in the future will depend on climate-related changes in lake DOC concentration and the chemical complexity of terrestrial DOM inputs.

Response of a North Temperate Lake to Interannual and Long-term Variations in Climate: Compounding Effects of Temperature, Cloud Cover, and Humidity

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Variations in climate have a significant impact on the energy and water budgets of lakes. These impacts are being monitored in the lake-rich region of northern Wisconsin (USA) where, like elsewhere, the climate has been getting warmer in recent decades. In this study, we focus on the effects of climate variability and change on the summertime energy and water balance of Sparkling Lake, a 64-ha inland lake with a mean depth of 11 m. A recent analysis of 18 years of data (1989-2006) has shown that not only is the climate of the region getting warmer, but reductions in humidity and cloud cover have led to increased solar radiation at the lake's surface. These trends have combined to produce significant increases in lake temperature and evaporation, along with notable interannual variations. The results of this study highlight the need to understand multiple atmospheric drivers of lake dynamics, as some factors may be as or more important than temperature alone.

Modeling Phytoplankton Community Re-organizations Under Global Change

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Phytoplankton community composition profoundly affects patterns of nutrient cycling and the dynamics of aquatic food webs; therefore predicting future phytoplankton community structure is crucial for our

understanding of how lake ecosystems respond to changing physical forcing and nutrient limitations. We develop a mechanistic model of phytoplankton communities that includes multiple taxonomic groups (diatoms, green algae and cyanobacteria), nutrients (nitrate, ammonium, phosphate and silicate), light, and a generalist zooplankton grazer. Each taxonomic group was parameterized based on an extensive literature survey. Major functional groups differ significantly in their key traits of resource utilization and these differences may cause shifts in community composition under changing conditions. We use the model to explore possible phytoplankton community re-organizations under different global change scenarios: an earlier onset and extended duration of stratification, with shallower mixed layer depths due to increased greenhouse gas concentrations and an increase in nutrient loading. Based on these scenarios, our model suggests that global environmental change will inevitably alter phytoplankton community structure and potentially impact global biogeochemical cycles.

Effect of Climate-Driven Changes in Wind, River Inflow, and Air Temperature on the Stability of a Small-to-Medium Sized Lake

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Changes in meteorology (temperature, wind, precipitation) will change the relative rates of production and consumption of turbulence in lakes with potentially profound ecological consequences. We use a validated one-dimensional, seiche-extended, k-epsilon model to predict the effect of climate change on deep winter mixing in a 35 m deep Swiss lake. Based on measured data, the lake is completely mixed in 60% of winters. A 20% increase in wind speed causes the probability of complete deep winter mixing to rise to 90%. The effect of a 30% increase in river inflow in winter and a 30% decrease in summer (the expected change in the European alps) has the opposite effect, with deep winter mixing probability decreasing to about 20%. An increase of +2C or +4C in air temperature has no significant effect on winter stability. It is only when the air temperature increases by +6C that the additional thermal stability is sufficient to overcome the mixing energy introduced by the winter winds, with the percentage of winter mixing events decreasing to about 20%.

Irregular "Sawtooth" Events in Long Time-Series of Deep-Water Temperature

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As a result of climate warming, time-series of deep-water temperature in many temperate lakes exhibit an irregular "sawtooth" structure, in which the temperature rises gradually over several years only to fall abruptly during occasional, deeply penetrative winter mixing events. Based on data from several lakes, we use two approaches to explain this behavior: a simple, illustrative stochastic model based predominantly on rising surface temperatures, and a more sophisticated physical model that accounts in more detail for the processes involved. We show that one of the consequences of climate change will be the suppression of penetrative winter mixing in many lakes previously considered to be holomictic, leading to an increase in the frequency of occurrence of multi-year (as opposed to single-year) "sawtooth" events, and to a prolongation of the mean duration of the periods of gradually rising deep-water temperature. This will lead to increased hypolimnetic oxygen depletion and enlargement of the anoxic zone.

Light Availability as a Useful Paradigm for Understanding Shallow Lake Functioning and Future Responses to Climate Change

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Lakes from the Pampa region of Argentina are typically large (> 100 ha) and shallow (~ 2m). Most of them are presently eutrophic or hypertrophic. The seasonal and inter-annual variability of these highly turbid lakes is strongly controlled by light availability. The region is presently experiencing increasing trends in precipitation, altered hydroperiod and steadily increasing agriculture pressure. Thus, we anticipate that a major effect of climate change on Pampean lakes will be related to changes in light availability, mediated by changes in water depth and background turbidity. We performed a mesocosm (3000 L) experiment aimed at investigating the effects of light availability on shallow, turbid systems. Our results are consistent with light-limitation theory: (i) light attenuation and (ii) primary production increased with light availability. Furthermore, the heterotrophic components provided additional evidence for the paradox of energy enrichment: (iii) herbivore density and (iv) the seston P and N content decreased, while (v) community respiration increased with light availability. Collectively, our results suggest that the anticipated climate changes will affect food web structure, energy fluxes and the carbon cycle of shallow lakes.

Dissolved Organic Matter, Regulators and Indicators of Bio-optical Conditions in Tropical and Subtropical Lakes

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Carbon cycling in inland waters is controlled by ecological and hydrological factors which are strongly influenced by local and regional environmental conditions. In particular, chromophoric dissolved organic matter (CDOM) is highly sensitive to modifications in climate and the watershed, while playing a key role in the fluxes of solar radiation, carbon and nutrients in the water column. This is particularly important in tropical and subtropical lakes, where highly dynamic processes of CDOM production and degradation are driven by elevated insolation, rainfall and productivity. As such, changing global climate and human disturbance have particularly important impacts on the capacity of CDOM to regulate ecosystem stability. In the present work, we compare the temporal and spatial dynamics of CDOM in lake ecosystems in East Africa (Lake Victoria, Lake Tanganyika) and Latin America (Cuenca del Plata). Primary productivity, nutrient dynamics and bio-optical conditions were found to be influenced by the state of the allochthonous and autochthonous CDOM. Degradation, mixing/dilution and production mechanisms directly control the optical conditions in these important ecosystems, varying spatially and temporally in relation to hydrological and ecological forcing functions.

CO_2 and CH_4 Emissions in Tropical Brazilian Hydroelectric Reservoirs: The Effect of Meteorological Systems**

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Time series of meteorological, water quality parameters, CO_2 and CH_4 were collected at the tropical reservoirs of Manso and Corumbá in Brazil. We analyze the collected data to study the effect of cold fronts on water quality parameters, stratification and GHG emissions. In Manso cold fronts had a strong effect over stratification. This is explained by a phase shift of the net surface heat flux which becomes negative during the frontal pass, cooling surface waters. This effect is enhanced by mechanical turbulent mixing due to stronger winds. Both effects tend to lower water temperature and reduce water stratification. The effect of a strong rainy cold front over Corumbá reservoir was observed. Stronger winds increased the mixing, resulting in a rise of turbidity and a drop of dissolved oxygen (DO) and of diffusive and bubble CH_4 fluxes. After frontal pass we observed a significant reduction of CH_4 bubble emission events and an increase in the net flux of CO_2 . We interpret the CO_2 increase as an effect of wind stirring which forced upper layer DO downward oxidizing CH_4 , producing CO_2 .

Arctic Lakes are Seives: Will Climate Warming Close the Pores?

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Ten years of high frequency temperature data obtained in lakes at the Arctic LTER site have been analyzed to show changes in heat content, Lake numbers and eddy diffusivities. Ln indicates the degree of instability of the internal wave field and is inversely proportional to eddy diffusivity (Kz). Large stratified lakes have lower Ln than small ones and greater connectivity between the epilimnion and hypolimnion. Ln in small lakes (1.6 ha) also indicate unstable waves occur. Kz in arctic lakes increase during low Ln events to values 10 to 1000 times molecular diffusivity. Our ten year time series captured a warm period at the beginning of the record, several years of cold, and now a trend of increasing heat content. Lake numbers are trending upwards such that Kz is near molecular values for longer periods of time. Processes such as remineralization which increase the specific conductivity in the lower water column will increase upward trends in Lake number.

Scaling and Modeling the Role of Lakes and Reservoirs in Climate Change

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The importance of very large lakes, such as the Laurentian Great Lakes, on local weather and climate is well known, and numerous studies exist incorporating fully coupled climate – lake modeling systems. Less clear is the impact of the innumerable smaller lakes that, for example, characterize the boreal forest – a globally significant ecosystem whose carbon balance is sensitive to the local climate. In most simulations of present day global and regional climate models, horizontal resolution is such that the vast majority of these lakes are subgrid-scale, and parameterization schemes would be needed in order to represent their impact. This overview paper reviews the current status of lake – climate system interaction research for both large (resolved) and small (parameterized) lakes. The role of lakes in the regional and global climate system, and the impact of climate variability and change on lakes will be examined. Uncertainty in climate change scenarios generated by global climate models will also be discussed as it relates to the response of aquatic ecosystems to projected climate change.

Increase in Bythotrephes in Lake Maggiore as Mediated by Refuge Increase Due to Climate Warming

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The global mean surface air temperature has risen 0.5 °C in the 20th century. Global warming is expected to affect plants and animals worldwide; however, the full dimensions of change are yet to be determined. Using correlation analysis, ecologists have sought linkages between climate change and phenomena such as earlier breeding of amphibians and birds, upward movement of alpine-nival floras, northward migration range of butterflies, and increased photosynthesis and changes in plant community composition. In aquatic environments, cyclical changes in biomass and density of plankton and in pelagic food web structure have been correlated with climatic indices such as NAO and ENSO that influence mixing and stratification regimes. A rise in ambient temperature is predicted to result in a eutrophication-like pattern, with increased density and biomass of plankton populations, due to enhanced rates of physiological and ecological processes. However, there may be indirect effects on populations as well. For example, earlier yearly warming and higher average water temperature will result in earlier, deeper and longer-lasting thermal stratification. The spatial and temporal development of a warmer, more food-rich epilimnion separated from a deeper, dark and cooler hypolimnion will allow for the establishment of a relatively warm, low-light water layer, in which zooplankton prey may be able to find a refuge from visual predation by fish. Refuge thickness is a very good predictor of Bythotrephes population density level in a given year in invaded lakes in Canada. Its spatial and temporal distribution over a year depends on trophic state and on climate-related factors. We analyzed long-term changes in population density and phenology of Bythotrephes longimanus in Lake Maggiore, Italy, to better understand the mechanisms responsible for its exponential increase in population density following the re-oligotrophication of the lake. We found that the establishment of a Bythotrephes refuge was positively correlated with the onset of seasonal population growth, and the latter with the population density level reached in a given year. Changes in refuge thickness resulted from changes in the depth of the top of the hypolimnion, while the thickness of the euphotic layer did not change over time. The Lake Maggiore case study provides a nice example of how climate-driven factors can influence the population density and phenology of a key invertebrate predator, and hence the functioning of the pelagic food web. The method for estimating the refuge size was originally described to address the causes of large interannual variability in the population density of the invader Bythotrephes in lakes on the Canadian Shield; our results show that it is suitable also for a large, deep lake, and that at least one indirect effect of climate change, altered refuge availability for a zooplankter from fish predation is potentially important.

Hydrology of, and Turbulent Fluxes From, Lakes in a Tundra Setting

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Although many northern regions are lake rich, our understanding of the sub-grid scale variability of these areas is very poor, and as a result out ability to model both the hydrology and the land/lake surface interactions with the atmosphere is extremely poor. This paper addresses these issues by studying two contrasting lakes in the Mackenzie Delta region of the Canadian Western Arctic. One lake, is in the Mackenzie Delta near the Beaufort Sea coast where the channel connection to the Mackenzie River dominates influx into the lake. The other lake is located at an upland site to the east of the Mackenzie Delta where a small contributing area dominates water flux into the lake. A comprehensive measurement program of all water and energy fluxes has been carried out at these lakes for 3 years. These data will allow us to integrate the water balance of each lake, and allow us to compare the turbulent fluxes of sensible and latent heat from lakes vs. land and therefore provide information on considering the role of lakes in lake dominated terrain.

The Structure of Plankton Food Webs Along Environmental Gradients

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Environmental change can influence the structure of lake food webs by altering the biogeography and trophic relationships of aquatic species. Examining contemporary patterns of food-web structure along environmental gradients can help predict food-web effects of environmental change. In this study, we sampled plankton from 50 lakes in British Columbia (BC), and used stable carbon and nitrogen isotopes to examine how trophic relationships among taxa (Daphnia, Holopedium, Diaptomus copepods, Cyclopoid copepods, Epischura, and Chaoborus) vary with total phosphorus (TP: 2-80 □gL-1), dissolved organic matter (DOC: 1-15 mgCL-1), mean summer surface water temperature (MSSWT: 12-22 °C), and altitude (15-1100 masl). Despite high turnover in the composition of species among lakes, the trophic structure of plankton communities was highly conserved along broad environmental gradients, suggesting considerable functional redundancy among zooplankton taxa. However, Diaptomus copepod species (Leptodiaptomus tyrelli, Hesperodiaptomus franciscanus, Skistodiaptomus oregonensis, Leptodiaptomus ashlandi, Acanthodiaptomus denticornis) differed in their relationship between trophic position and lake productivity, and were spatially structured along altitude gradients. Overall, these results suggest that environmentally induced shifts in species composition can alter trophic interactions in lake food webs.

Climate Change Induces Nitrogen Loading From Terrestrial to Aquatic Ecosystems

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Nitrogen causes significant degradation of aquatic ecosystems worldwide, and climate change in terms of temperature and precipitation may have major implication for nitrogen loading from terrestrial to aquatic ecosystems. We used stream nitrogen concentrations from 2,125 sites and climate data from 301 stations collected over 30 years from across British Columbia, Canada, to quantify and model the loss of nitrogen from terrestrial ecosystems and its loading to aquatic ecosystems. Results show that climate induced effect on nitrogen loading from terrestrial to aquatic ecosystems was stronger than the anthropogenic sources of loading. Elevated air temperature resulted in significant increase in nitrogen loading. Inorganic nitrogen loading increased more rapidly than organic nitrogen with increasing air temperature. We suggest that climate warming and elevated loading of nitrogen from terrestrial to aquatic ecosystems will have major implications for aquatic ecosystems.

Evidence for the Respiration of Ancient Terrestrial Organic C in Northern Temperate Lakes: Implications for the Terrestrial C Budget

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Lakes process and channel large quantities of organic and inorganic carbon from the surrounding terrestrial ecosystems, which fuels widespread CO2 super-saturation in the surface waters. The resulting CO2 emission from lakes represents a significant loss of terrestrial production. CO2 out-gassing in aquatic systems has been unequivocally linked to microbial respiration of terrestrial OC, but the nature of this OC respired in lakes is unknown. We present the first direct measurements of the D14C of OC respired by bacteria in temperate lakes. Our results demonstrate that a significant portion of the respired terrestrial OC is old, in the range of 1000-3000 years BP. Since the bulk OC pools in these lakes are relatively young, our results further suggest selective metabolic removal of an old but highly bioreactive terrestrial OC pool. At the regional scale, the mobilization of pre-aged terrestrial C and its biological degradation in freshwater systems suggests connections and lags between the fixation of C by the terrestrial vegetation and its return to the atmosphere that are more complex than currently accepted, and challenges current models of long-term C storage in soil reservoirs.

Flooding as a Driver of Lake Primary Production Over the Past 120 Years in Lakes of the Peace Athabasca Delta, Northern Alberta, Canada

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Human and climatic factors have altered flooding regimes in many of world's river deltas, but the impact of such changes remains poorly quantified on longer-term (decadal) timescales. This study quantified the response of delta lake primary production (measured as sedimentary pigments) to flood frequency using surveys and palaeolimnological analyses of lakes in the Peace-Athabasca Delta. Spatial surveys of 61 lakes over a range of flood frequencies showed that a lower flood frequency was associated either with elevated phytoplankton production or, in shallower lakes with an increased growth of emergent macrophytes and epiphytic diatoms. Consistent with this, palaeolimnological analyses of nine lakes showed that production of pigments increased during a 32-year period devoid of floods (1974-1996) but that the non-flooded control lake showed little response. Together these results suggest that response of delta lakes to future climate change and river regulation is broadly predictable and that future projections of water shortages will increase base levels of primary production in aquatic delta ecosystems.

Ecological Responses to Three Decades of Climate Variability in Sierra Nevada Lakes

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During the three decades since the late 1970s, precipitation in the Sierra Nevada of California has varied considerably as a function of ENSO events and other climatic conditions. Studies at Mono Lake, a large hypersaline lake on the eastern edge of the Sierra Nevada, and Emerald Lake, a high-elevation lake in the southern Sierra Nevada, span these three decades and reveal several ecological responses to the climate variability. The large runoff associated with strong ENSOs produced persistent chemical stratification in Mono Lake. As a consequence, vertical mixing was reduced, curtailing ammonium supply and, in turn, phytoplankton productivity. During periods of less precipitation, evaporative concentration led to weakening of the chemical stratification and eventually mixing of large quantities of ammonium into the euphotic zone and high productivity. In the high-elevation catchment of Emerald Lake, deep persistent snowpacks associated with ENSOs resulted in elevated inputs of nitrogen to the lake during snowmelt as well as rapid flushing of the lake and a short open water period. Results from analyses of sediment cores and simulation models add further perspectives on longer-term responses of these two contrasting aquatic ecosystems.

38 ky Record of the East Asian Monsoon from Sediments of Lake Biwa, Japan

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A combined piston and freeze-core continuous sediment record from Lake Biwa reveals new details of the response of the East Asian monsoon to the latest glacial-interglacial transition and post-glacial climate forcings and of the impacts of changing modes of prehistoric agriculture on the lake system. Times of wetter climate are recorded as increased burial of lake-derived organic matter and weathering-derived phosphorus in lake sediments. Organic carbon and phosphorus mass accumulation rates (MARs) are monotonously low in the Lake Biwa sediment record from 38 to 15 kybp. MARs double abruptly at 15 kybp and signal the onset of near-modern monsoonal conditions. A further dramatic increase in MARs occurs from 12 to 11 kypb. This brief increase roughly corresponds to the Younger Dryas, which is considered a return to glacial climate. The increase in Lake Biwa paleoprecipitation proxies indicates that winter monsoons actually did locally strengthen, but instead of creating glacial-like dry conditions they increased moisture delivery from the surface waters of the Japan Sea that became warm after rising sea level had allowed re-establishment of the warm Tsushima Current. Paleoprecipitation dropped to near-glacial levels by 10 kybp and gradually recovered to duplicate the high early post-glacial levels from 7 to 4 kybp. Organic carbon MARs increase from 4 to 1 kybp, a period when monsoon strength diminishes elsewhere in east Asia. The increased burial of organic matter is likely in response to early agricultural disturbance of the watershed and not an indication of locally wetter climate. MARs for the last millennium drop in response to establishment of rice paddies that replaced open-field farming around the lake and that sequester nutrients instead of liberating them.

Tracing Organic Matter From Dust Deposition Into Alpine Lakes Using Fluorescence Fingerprinting

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Climate change linked to global desertification is promoting a considerable increase of dust content in the atmosphere. Organic aerosols, associated with dust deposition, are known to influence the biogeochemistry of alpine lakes via the contribution of colored dissolved organic matter (CDOM) and to be an available substrate for bacteria. In this study, we characterized water-soluble organic carbon (WSOC) in dry deposition in southeastern Spain under periods of high and low Saharan dust intrusion events using UV-vis absorbance and fluorescence spectroscopy. We also examined dissolved organic matter (DOM) optical properties in an alpine lake in the Sierra Nevada, Spain and lake response to organic aerosol deposition. Using PARAFAC statistical modeling to resolve the dominant fluorescent components present in three-dimensional fluorescence spectra, we identified a semi-quinone like fluorophore (component 9) in the WSOC of deposition that was traced into the lake. At least three fluorophores, including component 9, were also found to contribute significantly to CDOM absorption in WSOC of atmospheric deposition. Our results suggest that fluorescence fingerprinting can be used to assess the significance of organic aerosol deposition in alpine lakes.

Climate-Driven Regime Shifts in High Arctic Ice-Covered Lakes

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Climate and sea ice observations have shown that the High Arctic has experienced several decades of rapid environmental change, with warming rates well above the global average. In this study we address the hypothesis that this climatic warming affects deep, ice-covered lakes in the region by causing abrupt, threshold-dependent shifts rather than slow, continuous responses. Our analyses by synthetic aperture radar (SAR) show that four meromictic lakes at the far northern coastline of Ellesmere Island, Nunavut have experienced unprecedented reductions in their ice covers over the last decade. These lakes are characterized by strong biogeochemical gradients and highly stratified biological communities. Temperature and salinity profiles of their upper water columns (5-20 m) indicate recent mixing, consistent with their loss of perennial ice and exposure to aeolian mixing. Although subject to six decades of warming at a rate of 0.5oC decade-1, these lakes were largely unaffected until a regime change in the 1990s. The results demonstrate that these limnologically unique far northern lakes are responding discontinuously to climate-driven change, and that these ecosystems have an indicator value beyond the regional scale.

Effects of High CO2 Concentrations Under UVR Exposures on Natural Phytoplankton Assemblages From a Lake

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This study tests the effects of elevated CO2 concentrations on phytoplankton photosynthesis and sensitivity to UVR. CO2 was supplied from an artificial CO2 source or produced by the mineralization of added colored dissolved organic matter (CDOM). For natural assemblages from Lake Giles incubated in situ, atmospheric CO2 concentrations similar to those predicted for the end of the century increased primary productivity 18%. No significant effect of CO2 was observed when UVR was excluded, indicating that UVR could play an important role on the availability of limiting elements. However, elevated CO2 concentrations also made cells more susceptible to UV, increasing photoinhibition under solar exposures. Sensitivity of photosynthesis to UVR was also affected by the interaction with other environmental variables such as acclimation to UVR and increased light attenuation by CDOM addition. UV inhibition modeled for midday in surface under elevated CO2 reduced primary productivity to 19% of potential production compared to 23% under usual CO2 levels in the lake. Among the factors contributing to the variation in estimated surface primary productivity, elevated CO2 concentrations were responsible of 11% variability.

Implications of Changing Temperature and Ultraviolet Radiation Regimes for Reproductive Success of Temperate Fishes

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Because fish reproduction is temperature dependent, the timing of spawning could be highly sensitive to climate change. For temperate species, an accelerated phenology could increase reproductive success by lengthening the growing season and increasing size-dependent overwinter survival. Climate change could also affect seasonal patterns of reproductive success by modifying ultraviolet radiation (UVR) exposure regimes. Fish are most susceptible to UVR during egg and larval stages. Because UVR levels fluctuate seasonally with changes in solar angle and water transparency, UVR-induced mortality risk will depend on the timing and location of spawning. Therefore, UVR exposure and temperature potentially interact to influence reproductive success. We examined seasonal patterns of UVR exposure and temperature in a highly transparent system to investigate UVR-induced mortality risk for bluegill over the course of the

spawning season. Specifically, we estimated UVR-induced mortality of bluegill larvae at depths where water temperature is 18°C, the temperature at which bluegill reproduce. We also explored potential changes in UVR-induced mortality for an accelerated spawning phenology due to climate change. Our results suggest that reproductive success could change substantially with increased temperatures.

Dissolved Organic Matter and Ultraviolet Radiation as Sentinels of Landscape-Scale Climate Change

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Dissolved organic matter (DOM) in lakes attenuates ultraviolet radiation (UVR) and, through adsorption, decreases the bioavailability of toxic metals and organic pollutants. Together, these factors serve to decrease the impacts of phototoxic contaminants that enter waterbodies from atmospheric deposition, runoff, or watercraft. Our recent studies have demonstrated that water quality characteristics and watershed management practices affect both the direct toxicity of UVR and fossil fuel combustion products in freshwater zooplankton. In addition, the source and levels of DOM are important regulators of UVR toxicity. For example, allochthonous DOM strongly attenuates UVR and strongly adsorbs contaminants, but is more photolabile than autochthonous DOM. Thus in systems that experience a change in watershed characteristics due to climate change, such as decreased precipitation (causing decreased inputs of DOM) or increased UVR (causing greater photodegradation of DOM), the impacts of UVR and phototoxic contaminants would increase significantly. Because lakes are integrators of watershed characteristics, such change will, over time, result in major changes in aquatic communities. Monitoring the characteristics of UVR attenuation and the sources and levels of DOM in lakes will likely provide sentinel measures of landscape-scale climate change.

Reservoirs as Sentinels and Integrators of Climate Change: Using Optical Tools

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We examine how variations in climate (a wet vs a dry year) may alter the UV optics and DOC sources and fate in two reservoirs with different watershed characteristics: Acton (90% agriculture, watershed:lake area 112)) and Burr Oak (11.6% agriculture, WS:L = 32). Optical signatures and DOC quantity and quality were examined during a wet and a dry summer at the inflow and outflow. In spite of high and seasonally variable chlorophyll levels (30-100+ ug/L) in Acton, particulate absorbance was most closely related to seasonal variation in inorganic particulates. During the dry year, Acton exhibited a slight increase in DOC quantity and no evidence of photobleaching. In Burr Oak DOC concentrations were consistently lower at the outflow versus the inflow sites. Lower DOC-specific absorbance and higher spectral slope at the outflow sites implicate photobleaching in Burr Oak. Reservoirs are likely to respond differently to climate-change driven changes in precipitation than are lakes. Changes in UV transparency and DOC dynamics will be related to watershed characteristics and depend more on particulate loading than variation in autochthonous productivity.

Predicting Species and Community Responses to Accelerated Global Change; What We've Learned From Montane Lakes and Ponds

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Heralded as sensitive barometers of global change, montane ecosystems have been active laboratories for field research, paleolimnological reconstructions of past environments, and serve as social and political bellwethers for emphasizing the global reach of anthropogenic impacts. Such environments have also been the site of enigmatic declines of species at the focus of conservation efforts. Predicting the spatial and temporal dynamics of such species in the future will require teasing apart which elements of species sensitivity to global change are plastic and which are fixed. The array of species found in montane ecosystems represent a diverse combination of physiology, behavior, and life-history shaped by each species evolutionary and ecological legacy. These unique combinations predispose some species, communities, and ecosystems to vulnerability and others to resilience in the face of natural and anthropogenic environmental change. Does the current range of heterogeneity in the physical, chemical, and biological environments experienced by species and populations correlate to individual or population-plasticity? Characterizing this heterogeneity may serve as a template for making predictions about species and communities under future global change scenarios. Drawing on examples from both my own work with amphibians in montane ecosystems and the broader literature, I will explore whether our current understanding of the variation in species responses to environmental stressors provides a constructive avenue for predicting the impact of future climatic change.

Assessing Impacts of Climate Change on Boreal Shield Lakes in a Multiple Stressor Environment

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Evidence for significant warming in northern and high altitude environments over the past 150 years is clear, and can no longer be ignored at temperate latitudes. Over the past three decades, central Ontario has experienced a lengthening of the ice-free season, summer droughts are becoming common, and maximum surface water temperatures now occasionally reach 29 degrees C, a level that stresses local biota. Documenting the effects of recent warming on lake water quality and ecology in southern boreal lakes is non-trivial as impacts may be blurred at temperate latitudes. Central Ontario, specifically, is subjected to multiple stressors that can mask or override climatic signals. For example, the re-acidification of lakes following drought has been well documented in this region. The relative importance of climatic factors, such as changes in temperature and precipitation, in affecting DOC concentrations also remains unclear, as other factors such as acid deposition history may have substantial influence. To assess the role of climate in influencing the limnology of boreal shield lakes, we examine over three decades of physical, chemical and biological data collected at the Dorset Environmental Science Centre and the Sudbury Cooperative Freshwater Ecology Unit in central Ontario, Canada. We use a variance partitioning procedure to quantify the linear and non-linear interactive effects of climate and acid deposition history on long-term changes in water quality parameters and lake biota.

Modeling Changes in the Frequency of Ice Cover on Lakes

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The direct physical impacts of climate warming on temperate lakes include higher water temperatures and shorter and less frequent periods of ice cover. Lakes that now do not freeze over every winter are expected to become entirely ice-free in the future. Physically, such lakes respond more sensitively to climate warming than lakes that freeze regularly every winter. Ice cover is a key factor regulating the timing of seasonal stratification, and complete loss of ice cover implies potentially drastic responses in lake biology. We present a simplified physical model that is capable of simulating the occurrence of ice cover on deep lakes that do not freeze over every winter, and which are therefore likely to react especially sensitively to climate warming. The model is applied to two neighboring lakes that differ morphometrically but are subjected to similar meteorological forcing. The predictive ability of the model is demonstrated by comparing simulations with historical ice cover observations, and the model is applied to investigate the sensitivity of the occurrence of ice cover to climate warming using different climate scenarios.

Spatial and Temporal Variability of Prairie Lake Hydrology as Revealed Using Stable Isotopes of Hydrogen and Oxygen

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Evaporation and groundwater fluxes are thought to regulate hydrologic variability in lakes of the northern Great Plains, but little is known of how these processes vary in time or space. To address this issue, we measured isotopic ratios of oxygen and hydrogen in water from 70 closed-basin lakes in southern Saskatchewan, Canada, endorheic sites which spanned a long gradient of salinity. Lakes exhibited synchronous seasonal changes in salinity (S = 0.78) and O isotopes (S = 0.84) during the dry summer of 2003, whereas coherence was reduced to 0.56 and 0.22, respectively, during the wet summer of 2004. However, despite evaporative enrichment of isotope ratios, hydrologic balances were regulated mainly by changes in water inflow (I) rather than evaporation (E) in both wet and dry years, with particularly strong influence of inflow in the dry southwestern region. Isotopic signatures also identified winter precipitation or groundwater as the main source of water to most lakes, despite only ~30% of annual precipitation being delivered in winter. Together these analyses revealed that although seasonal variability in lake chemistry was influenced by evaporation during summer, long-term mean chemical characteristics of prairie lakes were regulated mainly by changes in winter precipitation or groundwater influx.

Reactivity of Terrestrially Derived Dissolved Organic Matter in the Aquatic Ecosystem: Investigating Issues of Source, Biolability, Photolability and Nutrient Composition

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DOM concentration has increased in many lakes across eastern North America and Europe over recent decades. A similar trend is occurring in two glacial lakes we are studying in Northeastern Pennsylvania. While the mechanisms behind this trend are still debated, we ask what affect this influx will have on aquatic ecosystem function, and what is the chemical quality of this DOM? In order to understand how a characterized DOM source may impact an oligotrophic lake, water from a dystrophic pond was concentrated using reverse osmosis (RO) producing an allochthonous RO-DOM of low entrained inorganic nutrient content. Bacterial production and bioreactor lability assays revealed little response to RO-DOM alone (demonstrating recalcitrance), but following UVR exposure bacterial production increased 4-fold. Nutrient measurements and algal bioassays suggest release of phosphorus during UVR photolysis is more important in predicting bacterial response than production of labile carbon compounds. This RO-DOM of defined quality, which has been used in several in situ lake experiments of varying scales, is useful for determining how DOM influx from the watershed may influence microbial cycling within an oligotrophic lake.

Polar Lakes From Antarctic Peninsula as Sensors of Rapid Climate Change

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Lakes are the integrators of their catchments and are responsive to variations in landscape characteristics. In the polar regions the extreme environmental conditions produce an amplification of the landscape responses to climate changes and therefore lakes in these areas are still better sensors of these changes. The area of the Antarctic Peninsula is among those in the Earth were warming has been stronger during the last decades. Quick environmental changes associated to climate change, which are likely to reduce the strength of physical constraints for life in these Antarctic regions, would potentially modify the role of biotic interactions in structuring Antarctic lacustrine communities by mean of accelerating biogeochemical cycles in the catchment. An eco-climatic model using environmental and limnological characteristics of polar lakes at different latitudes has been constructed in order to estimate the

potential effects of climate change on freshwater ecosystems.

Effects of Reservoir Sedimentation on the Global Carbon Budget

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The number of artificial reservoirs has increased dramatically in last hundred years, a time when anthropogenic soil erosion rates have also increased in many areas. Previous estimates of total organic carbon burial in reservoirs are generally in the range of 0.2 to 0.4 Pg yr-1. However, a variety of data sources suggest that total global clastic sedimentation in reservoirs may be 35 Pg yr-1 or more. If this sediment averages 2% organic carbon then total carbon burial in reservoirs is ~0.7 Pg yr-1. In areas where soil surface erosion is a minor part of sediment yield the fractional organic carbon content may be lower. Considerable uncertainty regarding the magnitude of carbon burial in reservoirs results from: 1) rapid increases in numbers of reservoirs; 2) under-representation of small reservoirs in available datasets; 3) insufficient data on reservoir sedimentation rates and the organic carbon content of reservoir sediments; and 4) temporal change in sedimentation rates. Available evidence suggests that total reservoir carbon burial rates are likely under- rather than overestimated.

Spatial Variation in CO2 Flux From Large Freshwater Systems: Tropical Hydroelectric Reservoirs

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The exchange of metabolic gasses across the air-water interface is an important and integrative property of aquatic ecosystems and the connection of these systems to their terrestrial watershed. Gas flux is usually evaluated at a single, central site in lakes and reservoirs. Large hydroelectric reservoirs have been identified as potentially important sources of greenhouse gases (GHG) at the global scale. In tropical regions these systems are frequently associated with large watershed, which are complexes mosaics of different land uses. We evaluated spatial and seasonal variability in CO2 flux using both direct measurements and indirect calculation using continuous measurements of a set of variables using automated sensors in several large reservoirs (from 50 to 1400 km2) in Brazil. We found horizontal zones of pCO2 along the water surface; this heterogeneity was observed in all sampled seasons. Further, episodic mixing events were responsible for strong intensification of differences in pCO2 among zones in the reservoirs. Our analysis suggests that despite the considerable spatial variation in gas flux, the single sites near the dam tend to provide reliable estimates of reservoir-wide gas flux.

The Development of an Optical Indicator of Allochthony in Low DOM Lakes

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Regional and global environmental changes can alter the degree of allochthony in lake ecosystems. While studies have used a variety of methods to assess allochthony in lakes with high concentrations of dissolved organic matter (DOM), little research has focused on how differences in allochthony influence low DOM systems such as alpine lakes. Small environmental changes may substantially alter both the degree of allochthony and transparency of alpine lakes. Therefore, the effects of environmental change may be understood by examining how transparency varies in relation to allochthony. In the summer of 2007 we examined the relationship between several optical indices (spectral slope, PAR:UV ratios) and degree of allochthony (DOM/chl ratio) in 19 low DOM alpine and subalpine lakes in the Beartooth Plateau, WY/MT, USA. Both spectral slope (280-700nm) and PAR:UV (400-700:320 nm) showed a positive relationship with increased allochthony. The addition of UV transparency to assessment of optical changes in low DOM lakes provides a novel metric for understanding how lakes may respond to a variety of factors that influence allochthony such as climate change and nutrient deposition.

Alpine Lakes as Sentinels of Climate Change: Investigating the Effects of Ultraviolet Radiation and Temperature on Plankton Dynamics

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Alpine lakes experience low temperatures, high ultraviolet radiation (UVR), and are more responsive to climate change than lowland lakes at the same latitude, making them excellent sentinels of climate change. We examined the interactive effects of UVR, temperature, and zooplankton grazing pressure on natural phytoplankton communities in an alpine lake with a factorial-design and in situ microcosms. Treatment factors included temperature (8oC, 12oC), UVR (+/-), and trophic interactions (+/- zooplankton). DNA dosimeters in all treatments confirmed the potential for UV damage. Temperature had the strongest and most consistent effect on all four dominant phytoplankton taxa (Dinobryon sp., Fragilaria crotonensis, Cyclotella sp. and Asterionella formosa,), while UV and zooplankton grazing had a significant effect on three of the four species. Significant interaction effects included Dinobryon sp. with a three-way interaction and F. crotonensis and Cyclotella sp. showing a two-way interaction of temperature-grazing. The complex effects of these factors suggest that species- and trophic-level responses will be important in understanding the effects of future climate change in alpine lakes.

Dissolved Organic Carbon (DOC) Forcing of Plankton Dynamics in a Lake Ecosystem

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Climate-induced alteration of lacustrine DOC can affect planktonic communities by supplying carbon/energy/nutrients to heterotrophic microorganisms, altering light environments, modifying photosynthesis, and more complex indirect pathways operating through food web interactions. Concentrated natural DOC was added to water from an oligotrophic lake in replicated mesocosms (0.8 m diameter, 8 m deep) creating a DOC gradient (1.4, 2.5, 3.2, and 4.4 ppm). Bacterial production and bacterivorous protists increased within days of additions, and had relative maxima corresponding to the scale of DOC additions. Primary production, chlorophyll concentration, and ciliates increased proportionally to DOC additions, but with a time lag relative to heterotrophic protists. Biovolume of edible and inedible (gelatinous or >35 um) phytoplankton peaked at day 9 and 21, respectively. DOC increases as small as 1 ppm resulted in a shift in the relative abundances of Daphnia and calanoid copepods. Timing and magnitude of trophic-level responses to DOC, which suggest direct stimulation of prokaryotes with indirect stimulation of higher trophic groups via food web interactions and recycling of DOC-associated nutrients, will be further interpreted with first order autoregressive modeling.

Lakes as Sentinels and Integrators of Climate Change: Identifying Key Mechanisms by Merging Experimental and Paleolimnological Approaches

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Climate change influences the structure and function of lake ecosystems via numerous and complex mechanisms. To employ lakes as sentinels of current climate change, experimental and observational studies are used to explore the highly responsive nature of

lakes to climate forcing, along short-term to multi-decadal time scales. Lake sediments on the other hand can integrate millennia of lacustrine signals of change, and allow us to reconstruct longer-term patterns of regional climate variability. Integration of neo- and paleolimnological approaches enables us to not only reconstruct paleoclimate over longer time scales but to elucidate the mechanisms of the observed changes through experimental manipulation. I will review cases in which we have incorporated experimental and observational ecological studies into paleolimnological interpretations to decipher the mechanisms by which global change alters lake ecosystems, and propose future directions for exploration. A clearer picture of the links between lakes and climate change can be built by more tightly integrating research from these two realms.

Effects of Climate Change on Lake-Watershed Interactions

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The effects of climate change on freshwaters and their watersheds have largely been treated in isolation. Our studies have shown that many of the effects of climate change on lakes result from changes caused by climate to the terrestrial watersheds. Examples taken from a 37 year data set at the Experimental Lakes Area and 18 years of records for lakes in the Canadian Rockies include changes to water renewal rates, DOM concentrations, nutrient inputs, algal invertebrate and fish populations, concentrations of major cations and anions, and the burdens of mercury and organic contaminants. Many of the changes observed are the cumulative effects of a number of complex interactions that are all affected by climate change. As a result, lakes act as amplifiers of the effects of climate warming on entire cathcments.

Mechanisms and Consequences of Climate Change on Thermal Stratification in a Deep Lake

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Climatological forcing exerts a large influence on biogeochemical cycles within lakes. By altering the thermodynamic and momentum balance across the air-water interface, these processes exert changes across the entire water column that include a net warming and a net increase in lake stability. Both of these effects have been observed in Lake Tahoe over the last 40 years.

Using meteorological predictions from two GCMs, the range of future thermal stratification and temperature changes likely at Lake Tahoe are explored using a one-dimensional hydrodynamic model. Linear rates of change over a 50 year period, consistent with predictions from these GCMs or from global observations, are assumed for air temperature, relative humidity, wind speed and atmospheric longwave radiation. The results indicate that atmospheric warming alone cannot account for the historic rate of lake warming observed at Lake Tahoe. Rather, lake warming and alteration of the thermal stratification is occurring through multiple heat flux paths. The simulations show that within several decades, Lake Tahoe is likely to transition to a meromictic lake, resulting in major water quality and ecological changes.

Effects of a Changing Climate on the Stability of Lakes and Reservoirs: Causes and Consequences

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This paper reviews the effects of climate change on density stratification and mixing processes in lakes and reservoirs. The major changes in the driving factors are increased air temperature, increased or decreased precipitation and discharge, increased evaporation, and changing seasonal discharge patterns due to the disappearance of glaciers and changes in snow cover. It is often difficult to disentangle these climate effects from other anthropogenic forcing like nutrient inputs, hydropower or channelization of tributaries. In most cases, effects of climate change on seasonality are more pronounced than those on bulk properties. A shorter duration of ice cover and a longer duration of summer stratification have often been observed. A slow heating trend of the hypolimnia of deep lakes has been detected in lakes worldwide, whereas changes in surface water temperatures are more difficult to quantify due to their seasonal and interannual variability. If surface water temperatures increase faster - due to a high rate of climate warming - than the hypolimnetic temperature, this can lead to increased stability of deep lakes, potentially causing deep water anoxia and reduced nutrient recycling.

Methane Path From Sediment to Atmosphere in Tropical Hydroelectric Reservoirs

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Methane (CH4) flow data from 5 tropical hydroelectric reservoirs gathered in 12 survey stints over a 3 years time span are presented, representing a total of 567 flow measurements. The measured quantities were (1) sediment-to-water diffusive CH4 emission, (2) sediment-to-atmosphere CH4 bubble emission, and (3) water-to-atmosphere diffusive CH4 emanation. The sediment was the main methane source. In the water column there are methane oxidizing organisms residing within oxic floating detritus particles. The fate of these particles is to eventually become anoxic and turn into a distributed floating methane source before they settle on the bottom.

The following methane release averages were determined: CH4 bubble-flow to atmosphere 27.7±34 mg CH4m-2d-1(n = 204); diffusive emanation from water to atmosphere 36.0 ±32 mg CH4m-2d-1 (n = 237). The sum, 63.7 mg CH4m-2d-1, constitutes the total methane flow from the reservoir to the atmosphere, which is to be compared with 56.2 ±31 mgCH4m-2d-1 (n = 116), the average we measured for the sediment-to-water diffusive emission, which is 13% smaller. This sediment-to-water flow figure is close to what other groups measured for the arctic region during the warmer months (e.g. Huttunen et al. Boreal Environmental Research 11: 27-34 Helsinki 20 February 2006), hinting that in the sediment some concentration mechanism prevails over temperature effects. Sediment temperature was 18 to 26oC year round, and the surface-water temperature was 18 to 30oC. In other experiments we have found that in the water column either the distributed methane source or the oxidation sink can dominate in successive stretches of time. It is believed that the decisive forcing factor is oxygenation promoted by wind. However, we conclude that in our here presented longtime average the distributed methane source dominated, contributing with about 13% of the methane that reaches the atmosphere.

Deciphering the Effect of Climate Change and Separating the Influence of Confounding Factors in Sediment Core Records Using Generalised Additive Models

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Quantifying the effects of climatic change on freshwaters from sediment cores represents a difficult challenge. Dynamic Linear Models have been used successfully to model sediment core data, yet they are computationally complex, especially for high dimensional data, and adopt a terminology unfamiliar to many ecologists. Here we describe a new approach to modelling sediment core records, one that uses generalised additive models (GAMs) incorporating a continuous time autoregressive process to model residual autocorrelation. Species data are reduced to ordination axis scores that capture major changes in assemblages through time. Each set of axis scores is then modelled using a GAM with covariates representing trend and, where necessary, periodic components. Additional covariates can be added to the model to investigate the effect of other proxies (e.g. tree ring inferred temperatures) on species composition through time. The contribution to the model for each proxy at each observation in time can be determined and used to separate effects due to other factors from that of climate. We illustrate the approach using data from Kassjon, northern Sweden, and Loch Coire Fionnaraich, NW Scotland.

Climate Change Implications for Disease Ecology in Small Temperate Lakes

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Four years of monitoring meteorology, lake thermal structure and infection rates in Daphnia populations in eighteen lakes in southern Michigan have revealed relationships between climate forcing and disease ecology. Daphnia dentifera are parasitized upon ingestion of a non-motile yeast pathogen. Physical processes are necessary to resuspend and transport the pathogen to the pelagic zone. Along with other factors, such as resistance, host density and lake productivity, physical limnology contributes to the observed variability in infection rates. Lake thermal structure and mixing, driven by summer temperatures and the frequency and intensity of storm fronts, In the "coldest" year, epidemics started early and infection rates were high. In the warmest year, the strong ambient stratification provided resistance to mixing and the epidemics were late. Water temperatures also influence Daphnia feeding rates and therefore, susceptibility to infection. When autumn was warm and overturn late, epidemics persisted whereas epidemics crashed when fall cooling proceeded quickly. These observed patterns provide insights into potential climate change impacts on planktonic biota through bio-physical coupling.

High Organic Carbon Burial Efficiencies in Lake Sediments: Relationships with Oxygen Exposure Time and Mineral Phase Properties

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Lake sediments bury about half as much organic carbon (OC) as marine sediments, in spite of the small areal extent of lakes. Nevertheless, the factors triggering the effective carbon sink in lake sediments are still unclear. We compared the burial efficiency of organic carbon in a diverse set of lake sediments, focusing on the potential effects of oxygen exposure and protective sorption by minerals on the preservation and burial of OC. We found that in most lake sediments, OC burial efficiencies were considerably greater than in marine sediments. Further, OC burial efficiency was more strongly related to oxygen exposure time in lake than in marine sediments. On the other hand, OC burial efficiency was not related to the mineral surface area, a proxy of the sorption capacity of the mineral phase for OC. We conclude that the high OC burial efficiency in many lake sediments can primarily be attributed to a strong effect of oxygen exposure time, while protective sorption on mineral surfaces probably plays a subordinate role.

Biotic Responses to 20th Century Climate Change in Arctic and Subarctic Lakes Along Vegetation Gradient from the Northern Urals to Western Siberia

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The 20th century air temperature increase in the circumarctic north of 60ºN is well documented. However, the seasonal magnitude and spatial expression of arctic warming is highly variable with some areas showing cooling trends or no significant change in recent decades, e.g. parts of arctic West Siberia (ACIA, 2004). Diatom and chironomid changes were analysed in several 210Pb-dated sediment cores from a dozen lakes located along the northern taiga–arctic tundra vegetation gradient in the northern Urals and the West Siberian upland plateau. The degrees of compositional turnover and rates-of-change were estimated numerically.

The 20th century diatom and chironomid compositional changes and the rise in diatom accumulation rates in the northern Ural lakes correlate well with the regional summer temperature increase and with the overall circum-arctic temperature increase from the 1970s. There is no clear north-south gradient in degree of compositional changes, with greatest changes occurring in a northern taiga lake. Biotic changes in western Siberian lakes are more equivocal showing no significant response to the recent climate cooling.

Consequences of Glacier Retreat for the Planktonic Food Web Structure and Function of Alpine Lakes

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The rapid current retreat of glaciers constitutes one of the most prominent signs of climate change. As a result, many glacial lakes are becoming more transparent due to reduced glacier meltwater input, but also new turbid lakes are being created. Here we show that glacial and nonglacial alpine lakes do not only differ in physico-chemical characteristics but also in their planktonic food web structure. Results from DGGE fingerprinting revealed up to 49% dissimilarity in bacterial community composition between glacial and nonglacial lakes closely located at a similar elevation. Further, heterotrophic nanoflagellates (HNF) were absent in glacial lakes, coinciding with the highest bacterial abundance and production values. Data obtained from lakes representing a turbidity gradient indicated a threshold above which HNF are absent. In most glacial lakes, cladocerans were also absent and rotifers though in low abundance were dominant. These results suggest that the formation of glacial lakes creates favorable conditions for bacterioplankton (e.g., reduced mortality, less UV exposure, high P supply), but detrimental ones for 'keystone' groups such as HNF and cladocerans due to high levels of inorganic particles.

Evaporative Fluxes from Lake Superior

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Evaporation is a critical component of the water balance of each of the Laurentian Great Lakes, and understanding the magnitude and physical controls of evaporative water losses are important for several reasons. Recently, low water levels in the upper lakes have had socioeconomic, ecological, and even meteorological impacts (e.g. water quality and quantity, transportation, invasive species, recreation, etc.). This may be due to enhanced evaporation, but this is not known as operational evaporation estimates are currently calculated as the residual of water or heat budgets. Perhaps surprisingly, almost nothing is known about evaporation dynamics from Lake Superior. Few direct measurements of evaporation have been made from any of the Laurentian Great Lakes. This research is the first to attempt to directly measure evaporation from Lake Superior by deploying eddy covariance instrumentation. The direct measurements of evaporation are used with concurrent buoy, satellite and climate model data to extrapolate evaporation measurements across the entire lake. This data generates information that demonstrates the predominant mechanisms controlling evaporation from Lake Superior. This knowledge could improve predictions of how climate change may impact the lake's water budget and subsequently how the water in the lake is managed.

Lake James Assessment: Water Balance and Chemical Budget Models Developed in STELLA for the Water Quality Dynamics of Lake James in the Catawba River Basin of North Carolina

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The Lake James Assessment water balance (LJA-WB) and chemical budget (LJA-CB) models were developed in STELLA to quantify the hydrological and chemical dynamics of Lake James , an oligotrophic hydropower reservoir. This study ran from 1997 through 1999 encompassing ENSO neutral, el Niño, and la Niña conditions which initiated in 1998 and persisted through 2002 bringing the drought of record to the Carolinas . LJA- energy budget (EB) and WB results indicated water losses approaching 20% of total volume from the reservoir each year (7% evaporation and 13% unmonitored losses). The LJA-CB was developed around the LJA-WB in STELLA as a GUI-based modified Vollenweider/Chapra style empirical mass balance model for an incompletely-mixed laterally-segmented reservoir with an embayment. The LJA-CB is a heuristic tool which can be implemented in an afternoon to determine lateral zones of constituent assimilation and assumes hydrology is the driving variable for the system. By summing the daily loading, seasonal and annual loading estimates for each segment of the lake were calculated that were volume weighted and used to make inferences about spatial distribution of chemicals within the reservoir.

Effects of a Half-A-Millennium Winter on a Large Lake – A Shape of Things to Come?

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The winter 2006/2007 was most likely the warmest winter in Central Europe during the last 500 years. Winter is of special importance for deep lakes, as winter strength influences mixing dynamics which in turn is of fundamental importance for the up-mixing of nutrients and phytoplankton light supply. Here we analyse the hydrodynamical, chemical, ecological, and physiological (C:Chl ratio) response of deep Lake Constance to the extreme winter 2006/2007 and compare it to a decadal time series of winter limnology. Winter limnology 2006/2007 differed strikingly from the limnology of the preceding winter. However, a comparison with the long-term record suggested that at least the ecological response was not as extreme as expected from meteorology. This suggests that a deep lake can at least partially buffer extreme meteorological winters due to its internal multi-annual hydrodynamics. Consequently, the influence of an extreme winter in a specific year will hence depend also on the meteorological conditions during the preceding years in deep lakes. Hence, the half-a-millennium winter probably was only a first small view on the things to come with future climate warming.

Water and Isotope Chemistry and Carbon Dynamics Along a Lake Evaporation Gradient in Yukon Flats, Alaska

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Remote sensing studies indicate that lake areas are decreasing in some arctic regions as a consequence of recent increases in evapotranspiration and/or permafrost degradation. This has implications for fish, wildlife, and lake carbon dynamics. We analyzed water chemistry, water and carbon isotopes, and recent sedimentation of lakes in Yukon Flats National Wildlife Refuge (a 26,300 square kilometer area of wetlands, lakes, and rivers in interior Alaska) that represent a range of lake hydrologic settings and stages of lake-area loss. Dissolved organic carbon concentration, ultraviolet absorbance, and fluorescence correspond with lake evaporative state and suggest increasing lake water residence times and a shift of lake organic carbon source from allochthonous to autochthonous as lake-area loss progresses. Water chemistry correlates with geographic location (proximal to river, near lowland margins, or on highlands) and hydrologic connectivity with upland sourced groundwater or Yukon River water. Other lake carbon characteristics, including organic sediment accumulation and dissolved gases, were also evaluated. Our results reinforce that lake sensitivity to climate change is highly variable and is primarily a function of lake hydrology.

Integrating the Stream, River and Lake Components of CO2 Fluxes to the Atmosphere in Quebec's Boreal Region

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We developed some simple empirical rules to predict pCO_2 in a variety of streams, rivers and lakes of the boreal landscape near Eastmain, Quebec. These rules were then applied to upscale these three aquatic components in two randomly chosen sections of the landscape, each covering about 970 km^2, to estimate the individual contribution of each aquatic compartment (river, lake and stream) in terms of area and CO_2 fluxes. Annual C emissions from the ensemble of aquatic ecosystems of the two selected areas were calculated as 7650 and 4670 t C yr^{-1}, and the relative contribution of the various systems to this flux was greatly influenced by the presence or absence of large rivers. Lakes represented 66% and 98%, respectively of the surface area of aquatic systems, and contributed 28% and 79% to the net C emissions, respectively. Large rivers represented 32% and 0.8%, respectively, of the aquatic areas and contributed 35% and 3% to total C emissions. Streams on the other hand, despite their small areal coverage (1.3% and 0.7% of the total aquatic surface) accounted for a surprising 36% and 22%, respectively, of the total aquatic C emissions. We further examined how the variability in relative contribution of the various aquatic components is reduced with increasing spatial scale. Expressed on a whole-watershed areal basis, aquatic CO_2 emissions were estimated to range between 5 and 8 g m^{-2} yr^{-1}, or about equivalent to terrestrial NEP in that region.

Global Climate Change: A Paleoclimate Perspective from the World's Highest Mountains

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Glaciers are among the first responders to global warming, serving both as indicators and drivers of climate change. Over the last 30 years the Ice Core Paleoclimate Research Group at The Ohio State University has been engaged in a program of

systematic recovery of ice cores from high-elevation, low-latitude ice fields. The resulting climate records, along with other proxy data, have produced three primary lines of evidence for past and present abrupt climate change. First, high-resolution time series of □18O (temperature proxies) and net balance (precipitation proxies) demonstrate that the current warming at high elevations in the mid- to lower latitudes is unprecedented for at least the last two millennia. Second, the continuing retreat of most mid to low-latitude glaciers, many having persisted for thousands of years, signals a recent and abrupt change in the Earth's climate system. Finally, there is strong evidence within and around glaciers for a widespread and spatially coherent abrupt event ~5.2 ka that marked the transition from early Holocene warmth to cooler conditions that occurred through much of the world and was coincident with structural changes in several civilizations. Together, these three lines of evidence argue that the present warming and associated glacier retreat are unprecedented in many areas for at least 5000 years. The ice core evidence of the mid-Holocene event will be compared to available lake histories to get a larger scale understanding of both the magnitude and timing of this event.

Specific evidence of recent acceleration in the rates of ice loss of glaciers will be presented. The current melting of these ice fields is consistent with model predictions of both high latitude and vertical amplification of temperatures in the tropics. The ongoing rapid, global-scale retreat of mountain glaciers is not only contributing to global sea level rise, but threatening fresh water supplies in many of the world's most populous regions. The current and present danger posed by ongoing climate change and the human response will be discussed.

Lakes and Reservoirs as Regulators of Future Carbon Cycling and Climate

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Recent studies make it evident that a large share of the organic matter that enters inland waters from surrounding catchments is either retained or metabolized, rather than being passively transported downstream to the sea. Hence, the rate of deposition of organic carbon in lakes and reservoirs exceeds the rate of deposition in the world's oceans. As such, lakes and reservoirs may account for a substantial portion of the "missing carbon" sink resulting from anthropogenic fossil fuel burning and hence contribute to the regulation of climate. In addition, lake water is often supersaturated with CO_2 and CH_4, largely due to aquatic microbial mineralization of terrestrial organic matter. In this way, inland waters may act as conduits of terrestrial carbon to the atmosphere. The strength of this conduit depends on precipitation and runoff, which regulate the export of organic matter from land, resulting in a feedback from climate on the role of lakes in the carbon cycle. Moreover, the role of inland waters in the carbon cycle and land-sea-atmosphere interactions is changing drastically due to the construction of reservoirs.

15 Years of Greenhouse Gases Measurements From Boreal Hydroelectric Reservoirs and Lakes: Are They Different?

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Carbon dioxide (CO_2) and methane (CH_4) are the world's main greenhouse gases and are emitted from both natural aquatic ecosystems (lakes, rivers, estuaries, wetlands) and manmade reservoirs. The role of greenhouse gas emissions from freshwater reservoirs and their potential contribution in increasing atmospheric GHG concentrations is actually well discussed worldwide. This communication presents data of GHG flux measurements taken on reservoirs of various ages and sizes as well as on adjacent lakes and rivers from Canadian boreal ecosystems over the last 15 years. GHG emissions were measured with a floating chamber connected to an automated NDIR instrument giving real-time values. Our results indicate an increase of GHG emissions rapidly after flooding and a return to values of natural systems within 10 years or less. The return to natural ecosystems values is faster for CH_4 than for CO_2. Many processes related to production and emission of GHG are similar for both lakes and reservoirs, and some are specific to the creation of reservoir. A synthesis of our actual knowledge will be presented as well as a reflection on the contribution of reservoirs as regulators of climate change.

Temperature and Ultraviolet Radiation Interact to Control Invasive Warm-water Fishes

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Can climate induced changes in aquatic systems increase the success of biological invaders? We examined how temperature (T) and ultraviolet radiation (UVR) conditions can control the suitability of nearshore habitats for invasive warm-water fish species in Lake Tahoe, USA. DNA dosimeters were incubated in a number of nearshore sites to assess ambient levels of UVR-induced DNA damage around the lake. Larval warm-water fish were incubated in a subset of these sites to evaluate larval survival across a gradient of UV and temperature conditions. Larval fish survival was high in sites with low UVR:T ratios and decreased in sites with high UVR:T ratios for bluegill but not largemouth bass. Changes in temperature and UVR conditions of nearshore environments could relax current constraints on reproductive success and facilitate the spread of invasive warmwater fish species that have been historically excluded from these environments by unfavorable combinations of UVR and temperature. The implications of climate change for UVR transparency of lakes requires an increased understanding of the role of ultraviolet radiation in controlling aquatic invaders.

Climate Warming Slowed Down the Nitrogen Cycle in Lake Tanganyika

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In Lake Tanganyika (max depth 1470 m) climate warming caused a decrease in vertical mixing, a more stratified water column and reduced nutrient renewal rates from the hypolimnion which has lead to reduced primary productivity. Surveys in 1995-2004 examined the temperature structure and nutrient profiles in the water column. Comparisons with historic data show that while epilimnetic concentrations of dissolved silica increased since 1938, phosphorus decreased. Nitrate levels in the metalimnion decreased as result of decreased amounts of organic matter sinking out and decomposing below the photogenic zone. Nitrogen fixation is the largest source for organic nitrogen in Lake Tanganyika. Fixation rates likely decreased following reduced N demand as a result of reduced P supply. Historical evidence indicates that blooms of cyanobacteria were more common earlier in the century compared with the present. This finding contrasts strongly with the expected trend of increased N fixation and nuisance algal blooms in temperate waters caused by anthropogenic impacts including climate warming. In Lake Tanganyika massive blooms of cyanobacteria were natural and decreased as a result of the anthropogenic impact of climate warming.

Effects of Elevated CO2 Concentrations on Phytoplankton Biomass, Elemental Composition, and Species Composition

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We investigated the effects of elevated CO_2 concentrations due to climate change on chemical environment, biomass, elemental composition (stoichiometry) and competition between green algae and cyanobacteria. The experiments were performed in Limnotrons, 1000-L experimental ecosystems, where temperature, mixing and atmospheric composition were controlled. Algae were grown both in monocultures and in competition, at low (0.037%), moderately elevated (0.30%) and high (1.88%) CO_2 concentrations. Elevated CO_2 levels lowered pH and caused higher DIC levels. High CO_2 levels resulted in significantly higher biomass levels of the algae, which doubled or even tripled. In the competition treatments, the species succession showed similar temporal patterns, regardless of the CO_2 treatment. Furthermore, elevated CO_2 shifted the elemental composition towards higher C:P ratios, regardless of species identity. The shift in elemental composition towards higher C:P ratios implies that the overall food quality for aquatic herbivores could decrease under elevated CO_2 levels. This has been investigated in additional experiments with herbivorous zooplankton. Although food quantity may increase for herbivores, this potentially positive effect could be offset or even reversed by the negative effects of phytoplankton food quality.

Context Dependency of Climate Warming Impacts on Alpine Lakes

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A warmer and drier 20th century resulted in many lakes of the Canadian Rockies becoming clearer owing to ablation of small glaciers and reduced allochthonous inputs. Climate warming hypothetically caused abrupt changes in lakes during the glacial to non-glacial transition, shifting them from turbid and frigid conditions to a clearer, warmer, and more productive state. Comparatively, climate warming likely had lesser effects on alpine catchments that lack glaciers, improving water clarity by reducing terrigenic inputs. These hypotheses were tested by reconstructing the 400-yr histories of previously glacially-fed and non-glacial fishless alpine lakes using preserved sedimentary microbial pigments, chrysophyte cysts, diatoms, and stable isotopes. Synchronous declines in clastic sediment flux and increases in organic carbon levels marked the termination of glacial input into certain lakes during the early 1900s. Here, pelagic microbial diversity and primary production increased several-fold owing to the sudden appearance of deepwater phototropic bacterioplankton and chrysophytes. Phototrophic production and diversity increased only marginally in non-glacial lakes. Our findings highlight how glaciers will amplify the impacts of climate warming on lake ecosystems during the 21th century.

Flocculation of Allochthonous Organic Carbon – A Regulator of Organic Carbon Burial in Boreal Lakes?

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Precipitation and runoff is predicted to change in many areas due to climate change. Higher runoff leads to shorter residence times and higher concentrations of dissolved organic carbon (DOC) in boreal lakes. Higher DOC concentrations may result in enhanced flocculation of DOC relocating organic carbon from the water column to the sediments, and enhancing the role of sediments for the carbon dynamics. Along a gradient of boreal lakes with different DOC concentrations, we found that higher lake water DOC was related to lower sediment respiration rates. This suggests that increased allochthonous DOC input to lakes results in increasing carbon sequestration in the sediments. We extrapolated the data from a representative set of lakes to a regional scale to assess the importance of sedimentation processes and benthic mineralization, and to predict how altered DOC concentrations would affect the carbon balance in a changing climate.

Long Term Changes in Lake Ecosystems: The Question of When and How?

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The question whether lake ecosystems will respond gradually or abruptly to global warming is an ongoing debate. To address the issue of how and when lakes respond to environmental forces we tested the timing and the type of change for a suite of abiotic (ice, water temperature, stratification, nutrients) and biotic (phyto- and zooplankton) decadal time series. We classified changes as abrupt permanent, gradual permanent or abrupt temporary and tested whether there is a hierarchy in response at different system levels (i.e., physics, nutrients, phytoplankton, zooplankton), or different levels of integration (species, functional groups, total plankton communities). We chose three European lakes (Lake Erken, Müggelsee, Lake Constance), and Lake Washington in the USA – all of which have responded to recent warming. We hypothesize that changes at physical and at species level are of an abrupt nature, while compensation processes lead to more gradual changes at functional group levels or higher trophic levels per se. In order to determine possible regime shifts in the four different lake ecosystems we determined an aggregated ecosystem state index for abiotic versus biotic system variables.

Drastic Aridification of Southern Xinjiang, Northwestern China, in the end of the 8th Century: Geochemical and Ostracod Evidence from Lake Bosten

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A paleoclimatic record of the past 4700 years was reconstructed from a 720-cm-long core retrieved from Lake Bosten, southern Xinjiang, China. The age model of the recent 1400 years is well constrained by a suite of 12 AMS C-14 dates yielded from plant debris.

Ostracod abundance was low between AD 200-750, and the assemblage was dominated by deep-water dwellers, indicating a high lake level of ~10-20 m. The sediments contain a fair amount of carbonate detritus and show high d13C values in organic matter, indicative of the presence of C3 plants and humid condition.

Condition changed drastically at ~AD 750. Ostracods became very abundant and diverse. Shallow-water species increased significantly associated with eurysaline and epiphytic dwellers, indicating that the water depths were less than 5 m, and the environment was enriched in reeds and became desiccated frequently. The d13C of organic carbon shifted rapidly to heavy values, suggesting a major increase of C4 plants. The content of authigenic acicular aragonite increased conspicuously, implying strong evaporation and desiccation. This sudden aridification might have been responsible for the inevitable decline of the Silk Route.

Climate Change and the Phenological Plasticity of Zooplankton in Mountain Lakes

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Climate change is rapidly altering the phenologies of lakes. We hypothesized that the phenological plasticity of zooplankton species determines their ability to adapt to climate change. Our survey of eight fishless mountain lakes spanning a gradient in epilimnetic temperature of five degrees Celsius showed that omnivorous calanoid copepods Hesperodiaptomus arcticus reached high densities in nine months of the year, whereas herbivorous cladocerans Daphnia middendorffianna did so in three months. The analysis of a 16-year alpine lake dataset revealed H. arcticus adults and eggs decreased 65% and 50%, while D. middendorffianna adults and eggs increased 81% and 75% during above-average warm and dry summers (+1.2oC, -50mm rain). Further, H. arcticus adults and eggs decreased by 87% and 100% in response to an experimental warming of seven degrees Celsius, while D. middendorffianna adults increased by 95%. In comparison, warming suppressed egg production by 62% in montane H. arcticus, while stimulating egg production by 420% in montane D. middendorffiana. Therefore, several lines of evidence suggest that continued climate change will favor more phenologically plastic cladocerans, shifting mountain lakes towards greater herbivory.

Molecular and Isotopic Evidence for Climate-Induced Changes in the Algal Community and Primary Production in Lake Malawi (East Africa) During the Past 23,000 Years

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Biomarkers of aquatic algae and compound-specific carbon isotopes are used to examine changes in the algal community composition and primary productivity of tropical Lake Malawi. A major change in primary productivity and algal community structure of Lake Malawi occurred at the Pleistocene/Holocene boundary. From the Last Glacial Maximum (LGM) until ~11.8 cal ka, Lake Malawi was characterized by either low rates of primary productivity or algal productivity that was dominated by a group other than diatoms. At the start of the Holocene, diatoms and nitrogen-fixing cyanobacteria become more important contributors to primary productivity, similar to conditions observed in modern Lake Malawi. This transition is likely related to a shift in the dominant wind direction over Lake Malawi, resulting from a southward shift in the mean latitudinal position of the Intertropical Convergence Zone (ITCZ) during the last glacial. Throughout the entire 23 cal ka record, the effects of wind induced upwelling are important and may be the main control on the carbon isotopic composition of algal lipids through delivery of isotopically light CO2 to the photic zone.

Nonlinear Response of Dissolved Organic Carbon in Lakes to Global Warming

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Recent increases in concentrations of dissolved organic carbon (DOC) in lakes and rivers over large regions have been related to both changes in the climate and in the atmospheric deposition chemistry. Here we show with a dataset of 1041 boreal lakes along a 13° latitudinal gradient and 90 lakes along a 1000 m altitudinal gradient at 68°N that concentrations in DOC exponentially increased towards warmer geographical regions at lower latitudes and altitudes. Out of 16 meteorological, atmospheric deposition, catchment and morphometric variables tested, the variable best corresponding to this pattern was the number of days when air temperatures exceeded 0°C (Dtemp>0). Dtemp>0 was found to be a very good proxy for both meteorological and atmospheric deposition variables, but had the advantage over those variables to include the factor time which is decisive for how long biogeochemical processes can take place. We received highly significant relationships between lake- and year-specific Dtemp>0 values and DOC concentrations ($p < 0.0001$). Since Dtemp>0 is described as a nonlinear function of air temperatures with accelerated changes towards warmer geographical regions we conclude that a prolongation of Dtemp>0 as a response to global warming will result in an accelerated DOC increase towards warmer geographical regions.

Climate Effects on Lake Ecosystems: Lessons From Historical Time Series

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A present concern for lake systems and organisms is to predict how resilient they are under the rapid rate of current temperature increase to maintain ecosystem services and products. Physical responses to contemporary climate warming are already evident in lakes as indicated by increasing water temperature and intensified stratification. In this lecture I will highlight the empirical evidence for plankton responses to a changing thermal regime, as these organisms play a fundamental role for ecosystem functioning. Numerous studies show alterations in abundances and phenology patterns associated with temperature warming. The phenotypic plasticity to cope with climate change, however, varies greatly among organisms, which consequently can uncouple trophic interactions and alter the temporal characteristics of lake ecosystems. In species with a longer lifespan, progressively increasing water temperature can cause an abrupt shift in their life history after threshold levels of growing conditions are surpassed. Change in the physical structure further selects for specific phytoplankton cell types and consequently alters community composition of primary producers. These examples highlight that biological communities can amplify subtle environmental changes and that local adaptation provides resilience to environmental change.

Photodegradation of Chromophoric Dissolved Organic Matter Exposed to Simulated UV and Natural Solar Radiation

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UV-B radiation absorbed by chromophoric dissolved organic matter (CDOM) causes its photochemical degradation which subsequently increases the penetration of UV-B radiation thus magnifying deleterious effects on aquatic organisms. Samples of Meiliang Bay water filtered using 0.22μm Millipore filter in Lake Taihu were exposed to short-term (2-12h) simulated UV-B irradiation and long-term (1-12d) natural solar radiation in summer, which reduced their absorption in the UV and fluorescence intensity. The closer the distance to UV-B lamp, the longer the UV-B irradiation time, in other words: the larger the UV-B radiation dosage, the more obvious the decrease of CDOM absorption and fluorescence intensity are. The decrease of CDOM absorption and normalized fluorescence was coincidental to first order dynamics reaction. Three-dimensional excitation-emission matrix spectra showed the intensity and position of fluorescence peak changed during photodegradation process suggesting that the composition of CDOM changed when CDOM absorbed ultraviolet radiation. A significant linear relationship was found between a(280) and Fn(355) during photochemical degradation process. Therefore, it could be concluded that considerable CDOM photochemical degradation was recorded in the surface water layer in Lake Taihu.

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