Traces of sunlight in carbon biochemistry of shallow subarctic lakes

Marttiina V. Rantala, E. Henriikka Kivilä, Carsten Meyer-Jacob, Maxime Wauthy, Milla Rautio, Andrea Lami, Tomi P. Luoto, Liisa Nevalainen

RATIONALE

Sunlight fuels both the drawdown and evasion of carbon in shallow northern lakes that are important players in regional landscape carbon cycling. Global environmental change is altering the solar driven transport and transformation of carbon in lakes (Figure 1) — entailing potential for carbon feedbacks — yet the prevalent climate drivers and ensuing lake responses vary broadly between lake ecosystems and through time hampering upscaling efforts. Changes occurring within and beyond lake boundaries leave biogeochemical fingerprints in lake water organic matter — part of which settles to form lake sediment archives — that allow us to extend in space and time to elicit patterns and drivers of lake carbon cycling in remote northern regions.

Figure 2 Studied lakes in northern Finnish Lapland — including a transparent tundra lake low in organic carbon and a dark carbon rich lake in the mountain birch woodlands.

AIMS AND MEANS

We combined experimental and sedimentary approaches to explore synoptic interlinks between underwater light, aquatic carbon biogeochemistry, landscape carbon cycling and climate variability in two shallow subarctic lakes with divergent carbon and light regime (Figure 2). Below we focus on a few key elements of the ongoing work.

In situ experiments (treatments under full sunlight, sunlight without ultraviolet [UV] spectrum, no light) were first deployed on the lakes to determine how solar radiation — here focusing on UV degradation — shapes organic carbon concentrations, dissolved organic matter (DOM) optical (spectrophotometric and spectrofluorometric) properties as well as elemental (carbon to nitrogen [C/N] ratio), isotopic ($\delta^{13}C$ and $\delta^{15}N$) and pigment (photosynthetic and photoprotective) composition of particulate organic matter (POM) in the lake water.

Next we looked into elemental (C/N ratio), isotopic ($\delta^{13}C$, $\delta^{15}N$) and spectral (inferred lake water total organic carbon [TOC] concentrations and sediment chlorophyll a [CHLa]) properties of the sediments to decipher patterns and interconnections in aquatic primary production, terrestrial material transport and photodegradation in the lakes under natural and anthropogenic climate variability.

FINDINGS — EXPERIMENTAL

Our four week in situ incubation had little effect on the concentrations of dissolved and particulate organic carbon — yet biogeochemical properties of the carbon pools were markedly altered between the two light treatments (with and without UV).

UV exposure led to...

transformation of DOM quantity and quality (Figure 3) indicating photochemical oxidation of terrestrial high molecular weight organic compounds.

altered DOM fluorescence spectra and POM pigment composition (Figure 4) pointing to a relative increase in autochthonous contribution in lake water organic matter pool — despite an overall decline in algal production attributed to UV photoinhibition.

changes in elemental and carbon isotopic composition of POM (Figure 5) implying selective removal of isotopically light and carbon rich compounds.

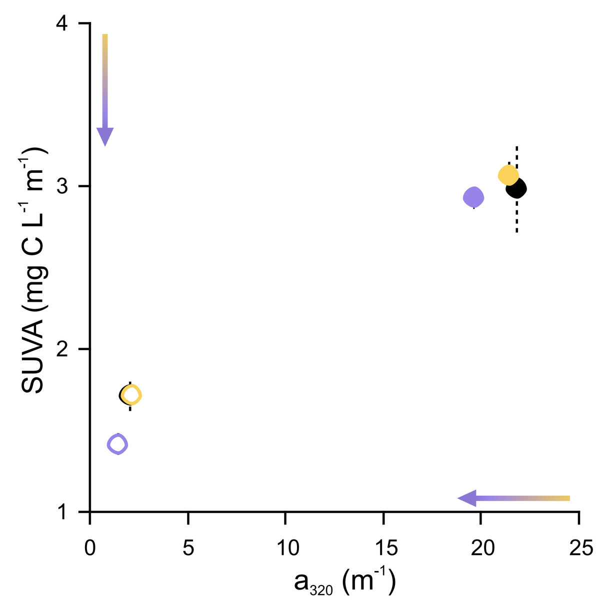

Figure 3 Absorption coefficient at 320 nm (a_{320}) displays an UV driven decline in colored dissolved organic matter (CDOM) concentrations — paralleled by declining aromaticity and contribution of terrestrial DOM as depicted by specific UV absorbance at 254 nm (SUVA).

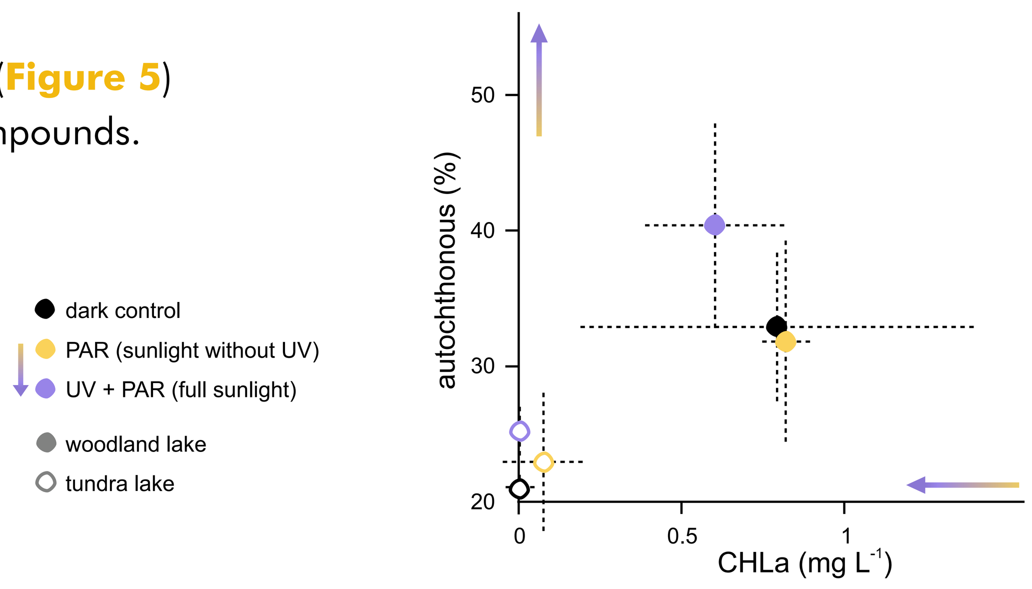

Figure 4 Parallel factor analysis (PARAFAC) of excitation-emission matrices (EEM) suggests increasing relative share of autochthonous DOM components while declining chlorophyll a concentrations indicate overall lowered algal production under UV exposure.

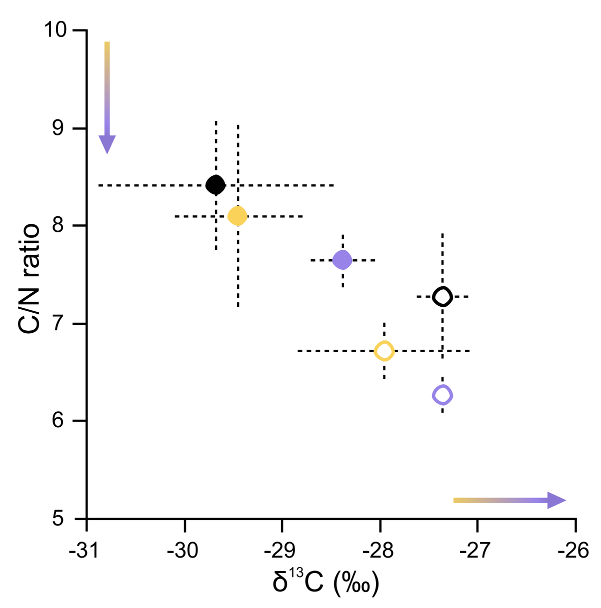

Figure 5 Increasing $\delta^{13}C$ values and declining C/N ratio under UV exposure indicate that photodegradation targets selectively ^{12}C rich organic compounds with high carbon content.

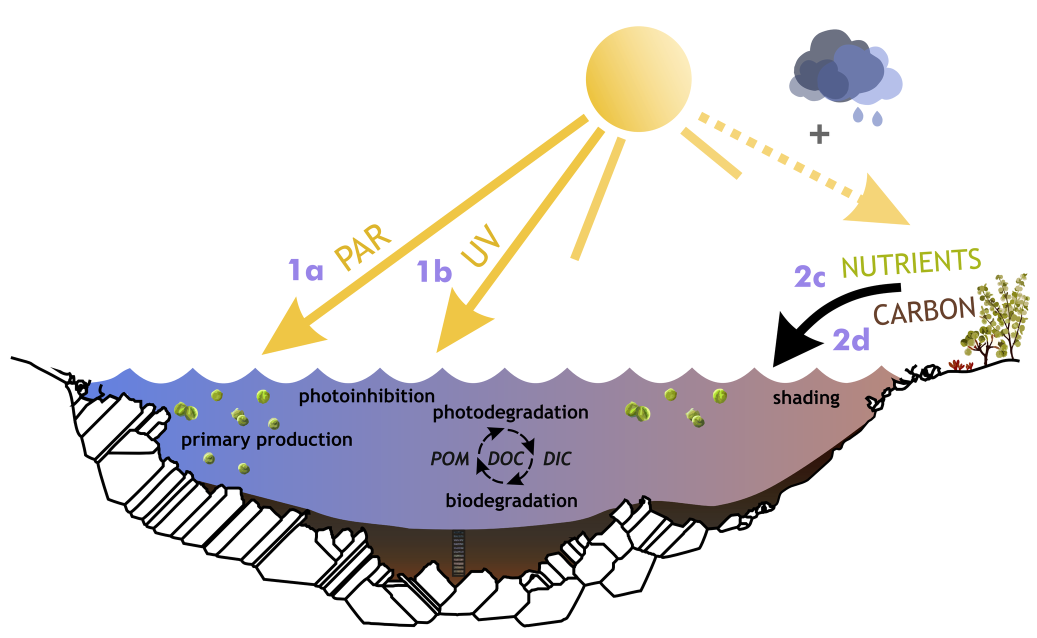

Figure 1 Schematic depicting key direct (1) and indirect (2) climate effects on fundamental abiotic and biotic components of the carbon cycle in shallow northern lakes — either likely to enhance photosynthetic carbon uptake (↓) or carbon mineralization (↑) or hinder either (↓↑). 1a) Increased photosynthetically active radiation (PAR) fuels primary production ↓ while b) increased ultraviolet (UV) radiation may inhibit production ↓ and accelerate rates of photo(bio)degradation ↑. 2c) Increased terrestrial nutrient input stimulates primary production ↓ yet d) terrestrial carbon inputs shade production ↓ and add substrate for photo(bio)degradation ↑ while also limiting the depth of UV penetration ↑. Lake sediments retain information of the changing carbon origins and of subsequent photochemical and biological alterations.

FINDINGS — SEDIMENTARY

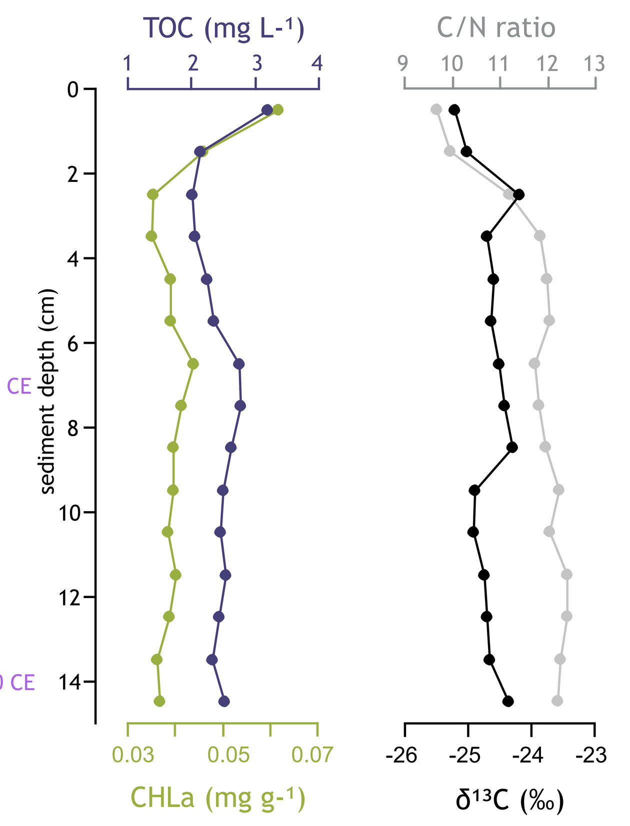

Figure 6 In the tundra lake, sediment chlorophyll a (CHLa) mirrored by carbon to nitrogen (C/N) ratio depict centennial variations in aquatic primary production — the changing production governs also variability in lake water organic carbon concentrations as indicated by the closely covarying inferred lake water total organic carbon (TOC).

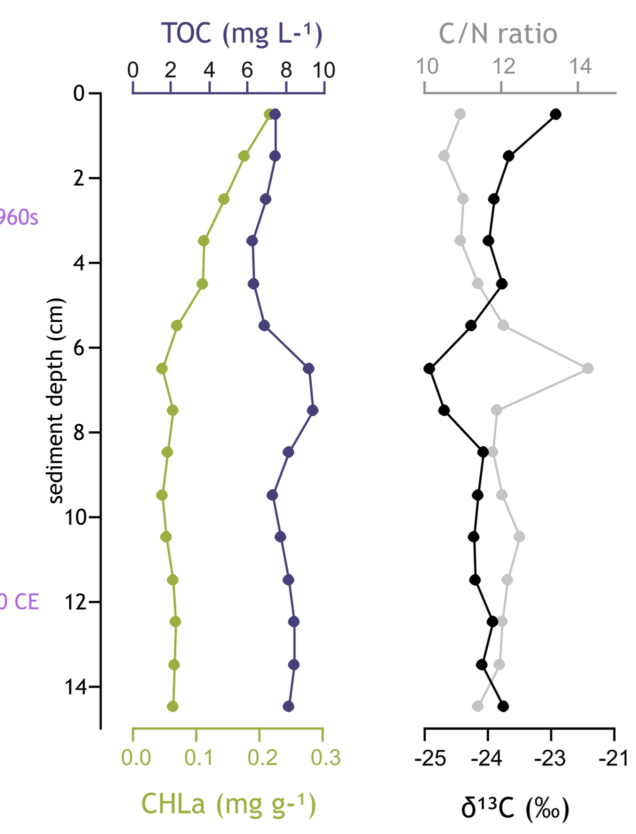

Figure 7 In the woodland lake, synchronously varying lake water total organic carbon (TOC), sediment carbon to nitrogen (C/N) ratio and carbon isotopic composition ($\delta^{13}C$) point to changing terrestrial carbon fluxes while shifting photodegradation rates could similarly contribute to the patterns — changes in aquatic production depicted by sediment chlorophyll a (CHLa) appear insensitive to either influence.

Above the treeline...

Despite characteristic ultraoligotrophic waters, biogeochemical fingerprints in the tundra lake traced primarily shifts in aquatic production (Figure 6) implying that — in context of climate variability of the past several centuries — the lake has at large remained disconnected from terrestrial carbon processing. We found no indications of change in organic matter photoprocessing which may relate to substrate limitation of photodegradation.

Below the treeline...

Shifts in sediment biogeochemistry in the woodland lake appeared to trace changes in terrestrial carbon inputs — yet the observed patterns could similarly be indicative of changing rates of photodegradation (Figure 7). Aquatic production appeared little affected by either influence even though both are tightly linked to underwater light that imposes strong control over benthic production in shallow northern lakes.

Under global change...

While we cannot pinpoint exact timing of the events both lakes carried evidence of increased aquatic primary production (and carbon burial) over the most recent period most likely in response to reduced lenght of the ice cover period under ongoing warming.

TAKE HOME

Irrespective of carbon and light regime — dissolved and particulate organic carbon pools in the studied lakes displayed sensitivity to UV driven photodegradation that is considered an important driver of carbon processing and evasion in shallow northern lakes.

Potential effects of photoalteration on organic matter biogeochemistry should not be overlooked in sedimentary studies — while additional proxies are needed to elicit its exact role due to overlaps in biogeochemical signatures.

Despite their divergent landscape position and carbon regimes both of the lakes displayed a uniform signature of increased aquatic primary production under global change — implying enhanced carbon uptake.

Organic matter biogeochemistry carries valuable information of aquatic carbon regulation in northern lakes — allowing insights into the prevalence and persistence of solar driven processes in divergent lake ecosystems prior to and under growing human perturbation.

For further information please do not hesitate to contact:
marttiina.rantala@helsinki.fi

ACADEMY OF FINLAND · UNIVERSITY OF HELSINKI · IRSA CNR · UQAC Université du Québec à Chicoutimi · CENTRE D'ÉTUDES NORDIQUES · Queen's University · GRIL