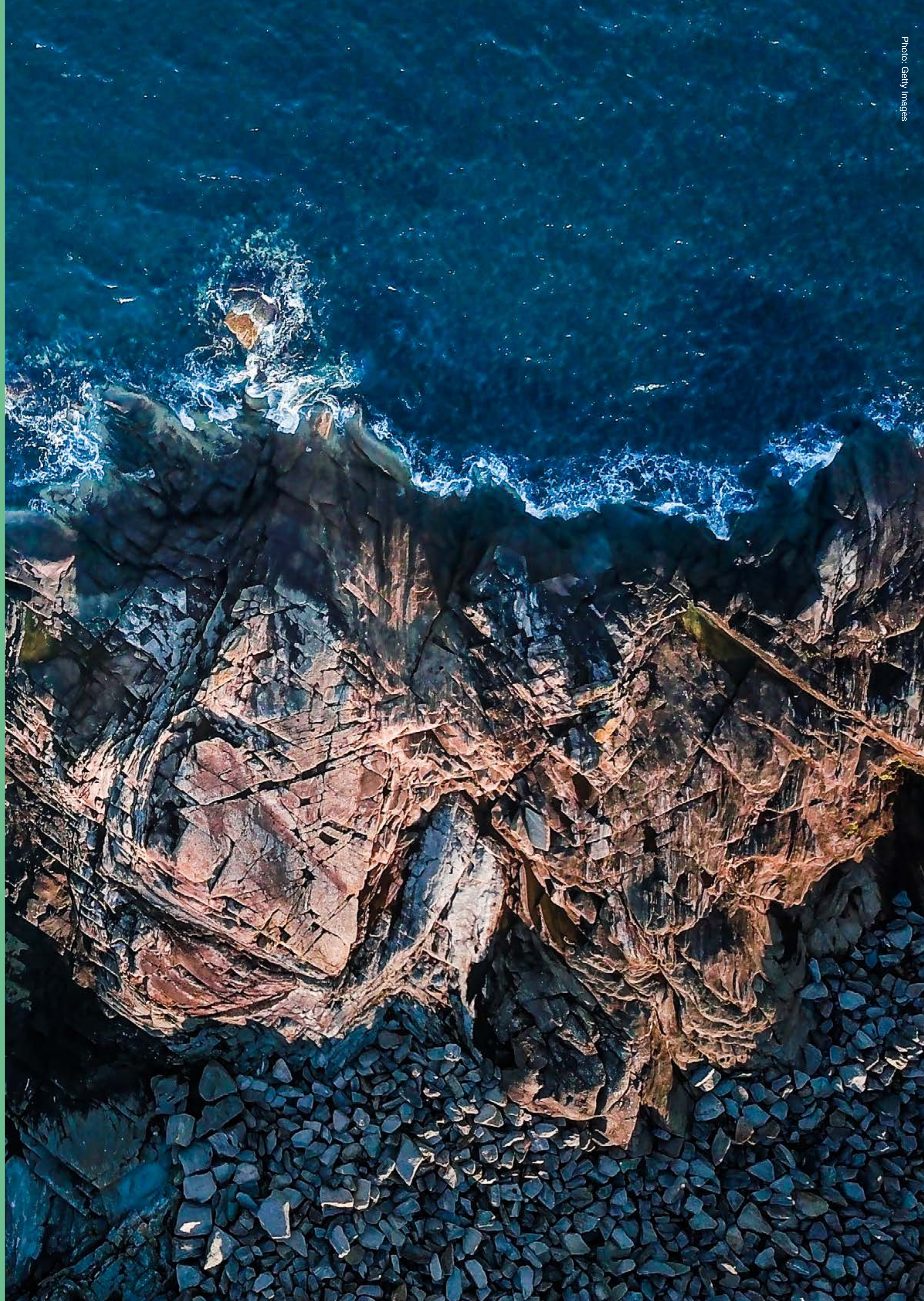
UNIVERSITY OF OSLO

Centre for Biogeochemistry in the Antropocene

Annual Report 2022

We study interactions and feedbacks between climate, carbon cycling and ecosystems in northern latitudes.



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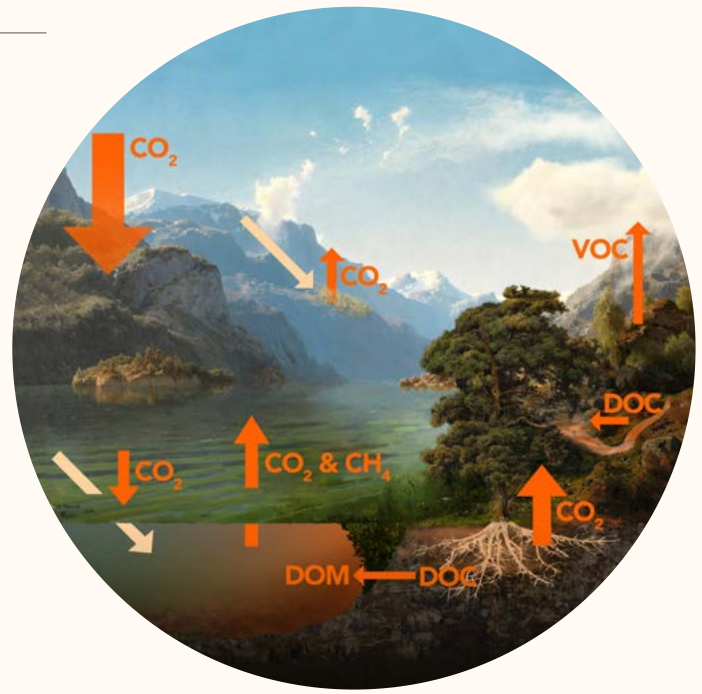

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Mission

We study interactions and feedbacks between climate, carbon cycling and ecosystem in northern latitudes. We assess and predict links from atmosphere to terrestrial and aquatic systems for carbon and other key elements, and feedback to climate by greenhouse gas productions in ecosystems. This is crucial for improvement of Earth system models, and thus to predict and counter anthropogenic climate change.

We educate the next generation of climate scientists in the fields of bioscience, chemistry and geoscience. We engage the public to implement strategies that help society and ecosystems reverse or adapt to climate and environmental changes.

Vision

Our shared vision is

- to develop and deploy basic science and novel approaches to understand biogeochemical cycles in a changing anthropogenic world.
- to educate students and raise awareness in society at large about the links between climate and ecosystem processes for the better of the future.

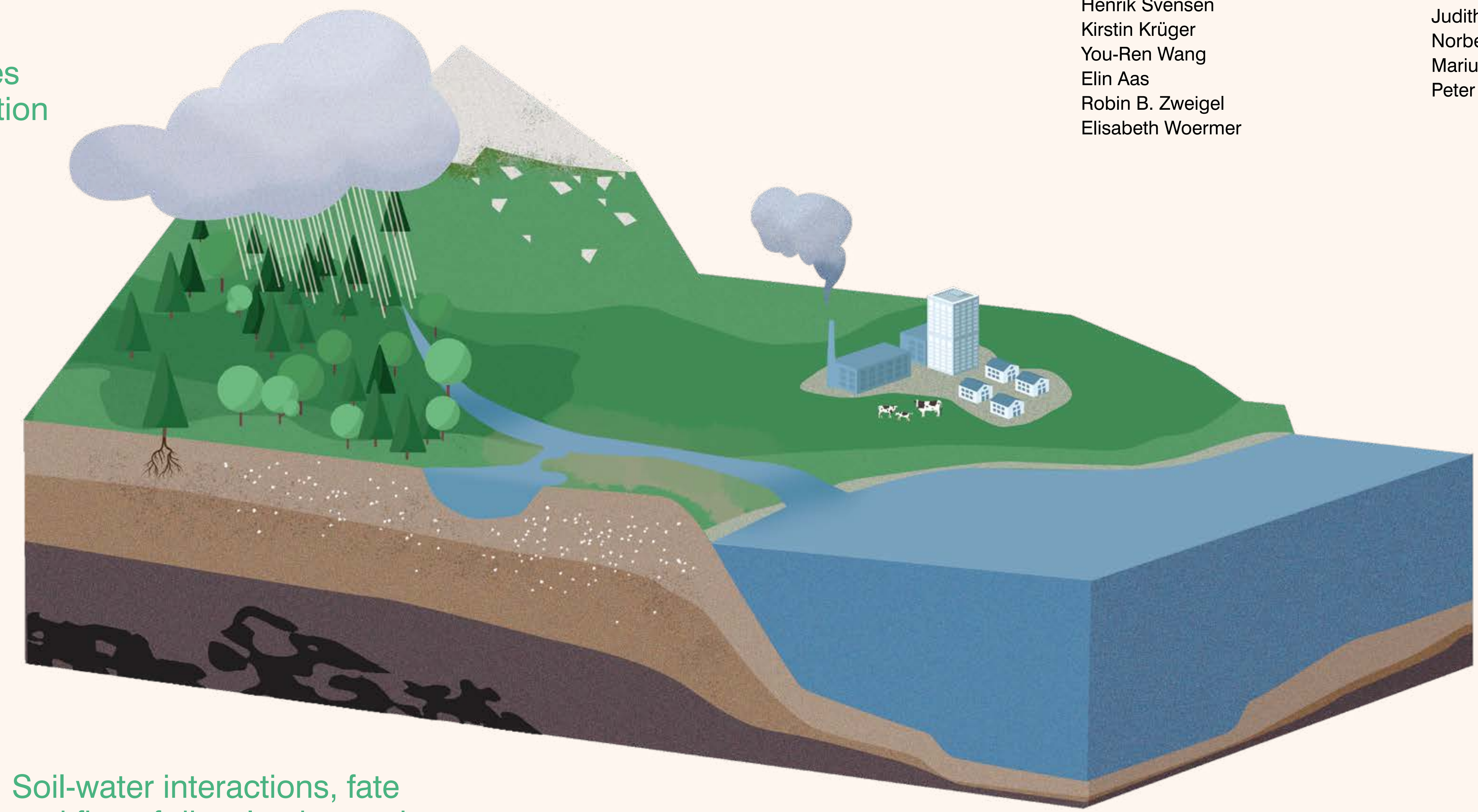
Values

We want to achieve excellence through

- Scientific rigorousness and openness
- Ethical practices in all areas of our endeavor
- Scientific accountability
- Respect, professionalism and dedication
- Sense of responsibility to transfer knowledge to the public
- Sharing of best practices and working as a team

CBA research topics

Faculty staff, postdocs and PhDs



Weathering processes and soil characterization

Helge Hellevang
Mats Rouven Ippach

Microbial genomics and metabolism

Alexander Eiler
Jing Wei
Laurent Fontaine
Eira Carlsen
Franck Lejzerowicz
Peter Dörsch
Inger Skrede

Atmospheric chemistry

Armin Wisthaler
Tomas Mikoviny
Baptiste Languille
Felix M. Piel
Wojciech Wojnowski
Anjitha S. K. Geetha
Alexander Håland
Wen Tan
Claus J. Nielsen
Niels Højmark Andersen

Soil-water interactions, fate and flux of dissolved organic matter and key elements

Heleen de Wit
Andrea Popp
Nicolas V. Parra
Jacqueline Knutson
Camille Crapart
Lina Allesson
Yu Yu
Francois Clayer
Xiang Lu

Climatic change and feedbacks

Terje K. Berntsen
Trude Storelvmo
Frode Stordal
Lena M. Tallaksen
Anders Bryn
Yeliz Yilmaz
Henrik Svensen
Kirstin Krüger
You-Ren Wang
Elin Aas
Robin B. Zweigel
Elisabeth Woermer

Permafrost dynamics, thaw, age, fate and flux of "old carbon"

Sebastian Westermann
Frans-Jan Parmentier
Jon Petter Omtvedt
Jing Wei
Alexander Eiler
Juditha Aga
Norbert Pirk
Marius Lambert
Peter Dörsch

Contaminants and carbon in coastal ecosystems

Katrine Borgå
Tom Andersen
Dag O. Hessen
Jan David Heuschele
Heidi Sjursen Konestabo
Sabrina Schultze
Alexander Eiler
Franck Lejzerowicz

Freshwater and coastal ecosystem responses

Dag O. Hessen
Tom Andersen
Elisabeth Alve
Lina Allesson
Aleksandr Berezovski

CLIPT lab

Anne H. Jahren
William Hagopian

Phytotron Lab

Ane Vollsnes
William Hagopian

ECODISTURB

Christina Nadeau
Dag O. Hessen
Manjana Milkoreit

Management structure

CBA is a joint operation between the Department of Biosciences, Geosciences, and Chemistry. This important interdisciplinary element of our centre is reflected in both the leader group and the board.

CBA researchers gathered for the annual meeting in Hurdal.

Participants in alphabetic order: →

Kristoffer Aalstad
Elin Ristorp Aas
Esteban Alonso-González
Tom Andersen
Michael Bekken
Aleksandr Berezovski
Terje Berntsen
Anders Bryn
Eira Carlsen
Francois Clayer
Camille Crapart
Peter Dörsch
Alexander Eiler
Cathrine Brecke Gundersen
William Hagopian
Dag Hessen
Mats Ippach
Jacqueline Knutson
Kari Kveseth
Holger Lange
Siyan Li
Erik Marthinsen
Christina Nadeau
Frans-Jan Parmentier
Norbert Pirk
Sabrina Schultze
Kamran Shalchian-Tabrizi
Silje Solevåg
Lena M. Tallaksen
Astrid Vatne
Femke Vianen
Rolf David Vogt
Ane Vollsnes
Jing Wei
Sebastian Westermann
Yu Yu

The leader group

Terje Koren Berntsen
Professor in geosciences

Armin Wisthaler
Professor of atmospheric chemistry, Department of Chemistry

Dag O. Hessen
Professor in biology and centre leader

Eira Carlsen
ECR representant

Yeliz Yilmaz
Centre coordinator

The board

Bjørn Jamtveit
Vice Dean (Prodekan) of Research

Einar Uggerud
Head of Department of Chemistry

Bernd Etzelmüller
Head of Department of Geosciences

Arne Klungland
Head of Department of Biosciences

The scientific advisory group

Tim Lenton
University of Exeter, Global Systems Institute

Vigdis Vandvik
Bjerknes Centre for Climate Research, University of Bergen

Marten Scheffer
Wageningen University & Research

CBA status and highlights 2022

"It is also finally recognized how tightly intertwined these two climate and nature "crises" are, and how they are mutually reinforcing. Such climate-nature interactions and feedbacks are to the core of most CBA-activities."

Dag O. Hessen
Professor in Biology
and leader of CBA
–

CBA can trace its origin to an SFF-proposal and collaborative efforts between the institutes of Biosciences, Chemistry and Geoscience back in 2010, yet has been in operation as a centre for 5 years, and this is the 4th annual report. It can safely be concluded that the relevance of biogeoscience in the context of carbon cycling, climate change and nature degradation has not decreased over these years, and also that CBA provides continuously new insights in this field as this report will testify.

The unique feature of CBA is (among other things) that it has its base in the institutes; Biosciences, Geosciences and Chemistry, and it thus make sense to circulate the leadership of the Centre. Given the number of activities and commitments of CBA it also makes sense to have a lead and a co-lead. Given the strong involvement of geosciences in the Centre, I thus proposed Sebastian Westermann (GEO) and Alexander Eiler (IBV) as lead and co-lead from 2023 on. This was approved by the leader group and board. I am personally very pleased with this, and I will still continue as an active member of CBA and head of the BioGov project (Fellesløftet). It has indeed been rewarding and inspiring to be head of CBA for these 5 years, and the topics we are working on has become ever more relevant given that our focus is on the two current crisis (the term crisis seems appropriate now), namely the climate crisis and the nature crisis. Thanks to all for inspiring cooperation so far, and it will continue for the years to come. This is the 4th annual report from CBA, and it testifies that we can be proud of our achievements.

This also offer a good opportunity for a brief glimpse on the background and development of CBA, which in fact extends at least back to 2010. By then there already was an extensive cooperation between the three institutes on issues related to climate and carbon cycling on the land-water interface, and this was manifested as a proposal for a Centre of Excellence (SFF) named "Oslo Water and Life (OWL) Research Centre" with the overarching vision to *"Exploring boundaries between and within biology, geosciences and chemistry to understand and predict the current and future role of water in relation to biogeochemical cycles essential to life on Earth"*. Sounds familiar? The proposed leader group was Frode Stordal (first 5 years) and Dag Hessen (last 5 years) with Rolf Vogt as co-lead for both periods. A number of the proposed key members are currently involved in CBA. The proposal was however not funded, but over the next years the cooperation continued to joint projects, and in spring 2015 (involving active correspondence on May 17th), there was an agreement to apply for "leading centre" grants close to current CBA, headed by Dag Hessen.

CBA was de facto in operation from 2017, and it was officially opened as a faculty Centre which was with a seminar in June 2018. All contractual issues were however first settled in 2019, meaning that the 5-year evaluation will not take place until 2024.

In fall 2021, the UN secretary general António Guterres stated in response the alarming news from the recent IPCC that this represented "code red for humanity". Hence it was instrumental that the international ambitions to reduce climate gas emissions were followed up and strengthened by the COP27 meeting in Sharm e-Sheikh in late fall 2022. To some extent it did, but it is also clear that we are heading towards somewhere near 2,5 °C global warming by 2100, unless we do even more. Shortly after, the UN Biodiversity Conference and (COP 15) was held in Montreal, and also stated that there is some kind of "code red" also for loss of nature and biodiversity. It is also finally recognized how tightly intertwined these two "crises" are, and how they are mutually reinforcing. Such climate-nature interactions and feedbacks are to the core of most CBA-activities, notably the large BioGov project that was started in 2022 – and properly presented in this report. The role of nature as a buffer against climate change both globally and locally was actually also the title and topic of one of the CBA-papers from 2022.

CBA has been represented in a number of activities, a very large number of presentations, meetings and lectures as well as a number of scientific presentations and papers. CBA has also been involved in the work with the UiO climate strategy, involving plans for an "Oslo sustainability Centre" (Bærekraftshuset) as well as the plans for "Oslo Science City" and the Lancet Countdown Report on climate as the major threat to global health. Other engagements and presentations related to these can be found in this annual report, but the overall message is a strong involvement of CBA in science, including cross-disciplinary activities as well as engagement in committees and outreach in a broad sense, including media.

CBA has also been deeply involved in the SFF-application ACT – Centre for Arctic Climate Transitions. The application made it to the second round, and the final application was submitted fall 2021. ACT was among the 11 proposals that was recommended for SFF by the international panel, but when it was decided to withdraw two from budgetary reasons, alas ACT was one of these.

The CBA the leader group in 2022 has been Dag Hessen (lead), Terje Berntsen and Armin Whisthaler, and was also supplemented by Eira Catharine Lødrup Carlsen, PhD-student affiliated with the BioGov project. The board has been research dean of the faculty, Bjørn Jamtveit, plus the heads of the respective institutes; Einar Uggerud (Chemistry), Bernd Etzelmüller (Geo) and Arne Klungland (IBV). The scientific board is Tim Lenton, Marten Scheffer and Vigdis Vandvik.

We look forward to 2023, and hope you enjoy this glimpse of the CBA activities in 2022.

Photo: Getty Images

Special focus

Permafrost Fact Sheet

Sebastian Westermann
–

Permafrost facts

Permafrost fact sheet
M-2353 | 2022

Permafrost currently covers 14 million km^2 of land area, but climate warming leads permafrost to thaw. If global warming is limited to +2 °C, about 75% of the permafrost will likely remain.

With today's climate policies, the world is on the course to 2.8 °C warming[1], and about half of the permafrost could disappear. If the world warms even more, only small permafrost areas will remain.

Thawing of permafrost has large consequences not only for ecosystems in Northern regions, but also for humans living in these areas.

Permafrost contains more carbon than currently contained in the atmosphere as CO^2. The carbon is not evenly distributed, but a lot is concentrated in smaller "carbon hotspot" regions.

When permafrost thaws, carbon-rich organic material can decompose, which leads to further emissions of greenhouse gas to the atmosphere. Therefore, permafrost is considered a potential tipping element in the global climate system.

Permafrost basics

Definition

Ground (soil or rock) that remains at or below 0 °C for at least two consecutive years.

Distribution

15% of the land area of the Northern Hemisphere (14 Mill. km^2), only small areas in the Southern Hemisphere (ice-free areas of Antarctica and high mountain areas in South America, Africa and New Zealand)[1,2,3].

Population living on or near permafrost

5 million

mostly in Russia[6].

Countries with permafrost

0.1% Norway[2,5]

0.2% Svalbard

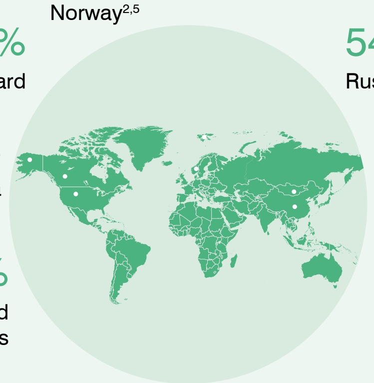
54% Russia[6]

28% Canada

2% Mongolia[4]

5% United States

7% China



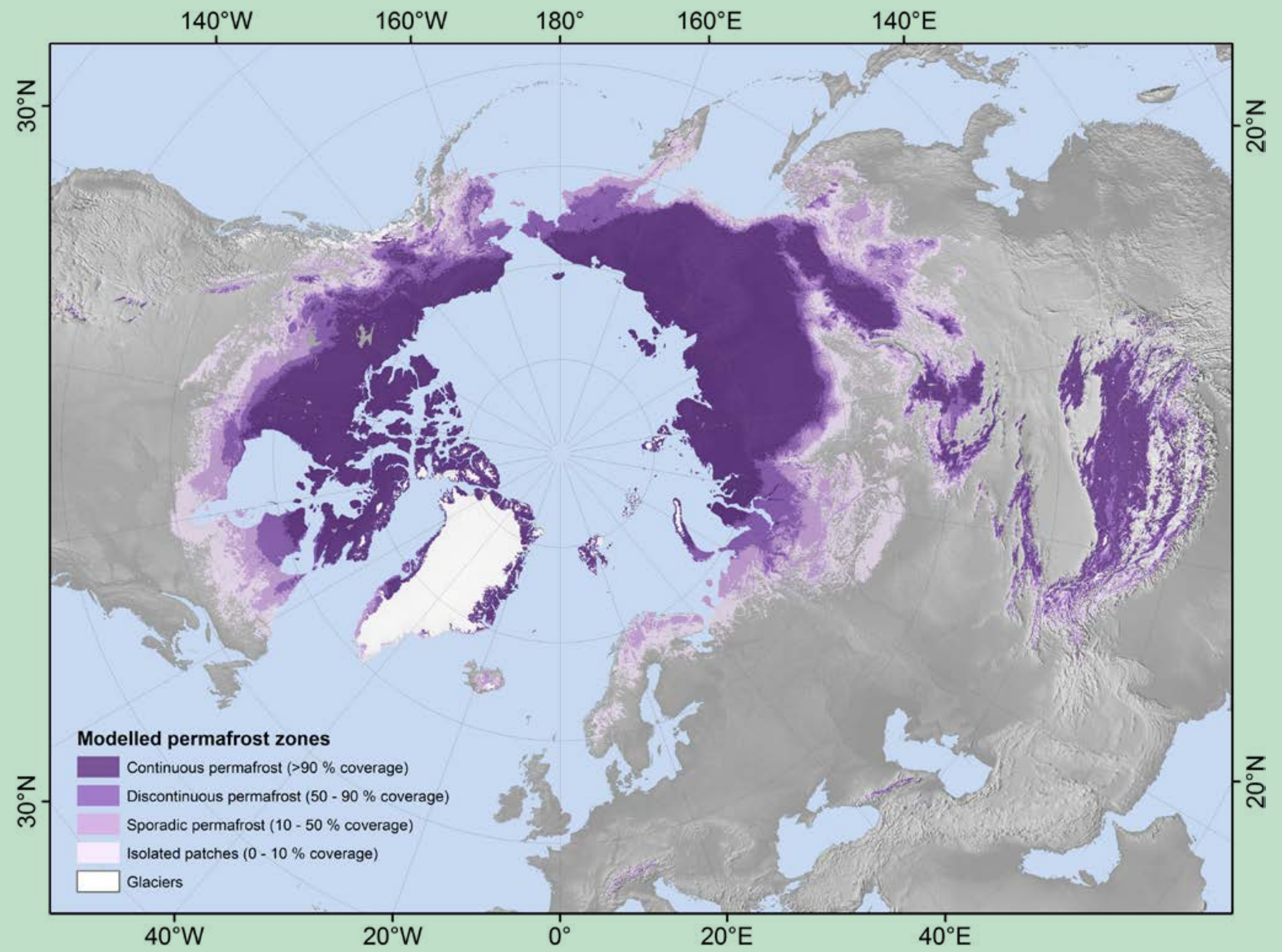


Figure 1: Permafrost distribution in the Northern hemisphere[2].

The permafrost fact sheet was compiled in the RUNPERM project funded by Miljødirektoratet.

It is available online:

Norwegian: *https://www.miljodirektoratet.no/publikasjoner/2022/november/permafrost*

English: *https://www.miljodirektoratet.no/publikasjoner/2022/november/permafrost-fact-sheet*

Photo: A,C: Sebastian Westermann; B: Thomas Opel, Alfred-Wegener-Institute, Germany

What does permafrost look like?

Permafrost can occur under forests, tundra, deserts, and wetlands. In most areas, it is not possible to see its presence at the surface, but in some areas characteristic "permafrost landforms" are found, which signal the presence of ice in the ground. Well-known examples are rock glaciers (A), ice-rich Yedoma permafrost (B), and peat plateaus (C). Rock glaciers occur in many cold mountain regions, including Norway[7] while Yedoma permafrost is found in Siberia, Alaska and North-west Canada. It is characterized by extremely ice-rich ground, which was formed in the last glacial period when these areas were not covered by ice sheets[8]. Peat plateaus consist of peat mounds with an ice-rich core. They are typically 1 to 5 meter high and occur in peatlands of the sub-Arctic, including Norway[9]. Both Yedoma permafrost and permafrost peatlands are "carbon hotspots" which are strongly affected by climate change[8,10].

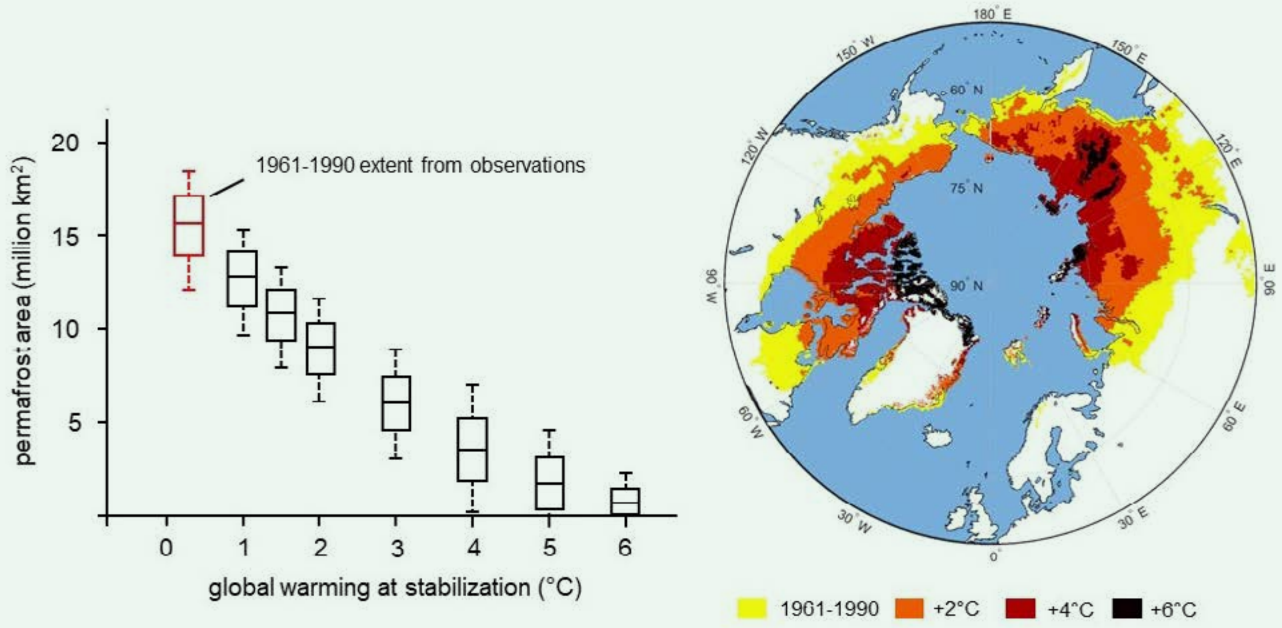


Figure 2: Remaining permafrost area under future global warming scenarios, with the 19961–1990 permafrost area derived from observations as reference[15] (0 °C warming corresponds to pre-industrial climate). The study suggests that several million km² of permafrost can disappear even if global warming is restricted to 2 °C.

How much carbon is contained in permafrost ground?

The total amount of organic carbon in the permafrost region is estimated to 1200 Gt (1 gigaton = 1 billion tons) carbon (C). As a comparison, the atmosphere at present contains 870 GtC, mostly in the form of carbon dioxide, and about 10 GtC are added from fossil fuel burning each year[11]. Permafrost carbon is the result of slow accumulation of organic material over thousands or even tens of thousands of years. Although "carbon hotspots" cover only a small part of the permafrost region, they contain about two thirds of the permafrost carbon[12].

Permafrost thaw in a warming climate

The majority of the permafrost has warmed in the last decades[13], and permafrost has already disappeared in many areas, including in Norway. In the arctic and thus in most permafrost areas, the observed warming trend is higher than the global average[14]. If warming is limited to 1.5 or 2 °C, permafrost will persist in most of its present range[15]. However, it will likely disappear from many areas where permafrost temperatures are already now close to 0°C, e.g. permafrost peatlands in Norway[9]. In high emission, "business as usual" scenarios, the largest part of today's permafrost will thaw[15]. In this case, permafrost may only survive in high-arctic regions of Canada, Greenland and Siberia.

How could permafrost affect global warming?

When carbon-rich permafrost thaws, microbes can decompose the previously frozen organic material. This produces greenhouse gas emissions, in particular carbon dioxide and methane. As an example, the release of only 5% of the permafrost carbon pool corresponds to around six years of current global fossil fuel emissions. This makes it more challenging to reach climate

Ice-rich ground near Utqiaġvik (Barrow), Alaska.
Credits: Sebastian Westermann.

"Future projections on permafrost greenhouse gas emissions are highly uncertain and more research is urgently needed to improve the climate models."

stabilization, especially the 1.5 and 2 °C targets[16]. As permafrost contains such large amounts of carbon, these emissions must be accounted for in climate projections. However, future projections on permafrost greenhouse gas emissions are highly uncertain and more research is urgently needed to improve the climate models. Field observations and atmospheric measurements show that the permafrost regions are currently a small sink of CO_2 (-0.7 to -1.4 Gt CO_2 /year), but a net source of methane (0.03 Gt CH_4/year, corresponding to 0.8 Gt CO_2 equivalent /year on a 100-year time horizon)[17]. While vegetation growth at the moment compensates for permafrost carbon loss[17,18], this is likely not the case if permafrost thawing intensifies in the future[19]. The thaw behavior of the "carbon hotspot" regions is particularly important. They not only contain large amounts of carbon, but are also rich in ground ice which can lead to rapid collapse of the ground and the formation of lakes and ponds once a site-specific warming level is exceeded[20]. While model projections for the hotspot areas are especially uncertain, the greenhouse gas emissions from these relatively small regions could be of similar magnitude as emissions from all other permafrost areas combined[21].

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Taking nature into account: Do we grossly underestimate the Norwegian GHG emissions?

Dag Olav Hessen
Professor, Department of Biology

The Norwegian emission of greenhouse gases (GHGs, primarily CO_2, CH4 and N2O) has for the past 30 years ranged between 50–55 million tonnes (Mt) CO_2e (CO_2 equivalents, where the warming potential of all gases is converted to CO_2 units). For 2021 the emissions were down to 48,9 Mt CO_2e, but the emissions from oil and gas industry have in fact increased from 8,2 Mt in 1990 to 12,1 Mt in 2021, and relative to the Norwegian goals of emission cuts by at least 55% relative to 1990, the development is not very promising.

An important premise both for Norway and globally is that over time we need to have negative emissions, meaning that uptake must exceed emissions. This can be achieved by strong cut in emissions combined with an increasing net uptake of CO_2 in ecosystems, first and foremost by CO_2-uptake in forests. Photosynthesis is by far the largest ecosystem service today, and currently the only means of globally significant C-sequestration from the atmosphere. It comes also without costs and energy use. Globally ecosystems on land and oceans take up more than 50 % of human CO_2 emissions, in itself a key argument for preserving forests and provide afforestation. Due to increased forest volume, mainly thanks to massive forest planting campaigns some decades ago, the net uptake of CO_2 by forest has actually increased. This has motivated political incentives towards intensified forest planting, eventually also boosted by nitrogen fertilization. To estimate net CO_2-uptake by forest is quite straight forward, yet the net climate effect is disputed due to reduced albedo effect of coniferous forests, plus that N-fertilization could in fact also promote release of N2O as an intermediate product in the denitrification process.

Boreal forest and lakes or wetlands may play opposite role for the greenhouse gas balance. While forests generally have net uptake of CO_2, boreal lakes are typically major conduits of CO_2 and CH_4. For this reason, and others, we should reconsider the Norwegian GHG-budget. Credits: Dag O. Hessen.

These estimates on the national GHG-budget are important, but how accurate are they, and do we miss something? Unlike most terrestrial and marine ecosystems, lakes, and notably boreal lakes, are net emitters of CO_2, and also significant sources of CH_4, in some cases also N2O. This is also evident from the general supersaturation in boreal lakes (cf. the CBA-studies by Valiente et al. 2022), confirming previous studies from Norwegian lakes (Yang et al. 2015). Since dissolved organic carbon (DOC) generally stimulate microbial production and degassing of CO_2 and CH_4, this implies that increased runoff of DOC to lakes, which may be boosted by more forests, will increase the GHG emissions.

In Sweden, it has been argued that there is a major flaw in the national GHG-budget since the significant release of GHG from lakes and wetlands are hardly accounted for (Lindroth and Tranvik 2021). They argue that "… Sweden's land sink, which is critical in order to achieve zero net emissions by 2045 and negative emissions thereafter, is reduced to less than half when accounting for emissions from wetlands, lakes and running waters. This should have implications for the development of Sweden's mitigation policy." Tranvik presented these findings in a CBA-seminar in fall 2022. In Norway, all major landscape elements are included in the GHG budget. It is estimated that forest in Norway has

"We only report emissions on Norwegian territory, meaning that CO_2 released from all exported oil and gas is not accounted for, neither is our contribution to international flights or other transport of goods. "

an annually net uptake of ca 25 Mt CO_2e, while release, mainly from drained bogs, is estimated to ca 4 Mt CO_2e (Miljødirektoratet; https://miljostatus.miljodirektoratet.no/tema/klima/norske-utslipp-av-klimagasser/). Since release of CO_2 and from lakes and rivers are hardly accounted for, and given that 17000 km2, or > 5 % of the land area are lakes, is seems highly likely that we also in Norway grossly underestimate their role in the national GHG budget, and that the ongoing work at CBA with measurements of GHG-concentrations, and estimates on GHG production, could help improving these estimates.

There is another, well recognized, and official reason while the national contribution to the global GHG emissions is underestimated. We only report emissions on Norwegian territory, meaning that CO_2 released from all exported oil and gas is not accounted for, nether is our contribution to international flights or other transport of goods. Since Norway imports a wide range of products, this major part of our consumption-related GHG-emissions are not accounted for in the national budget. While the total emissions of GHGs from the Norwegian mainland are almost negligible compared with larger nations, another picture emerge if we look at *per capita* emissions where we are quite high despite our hydropower energy (7,7 tonnes per individual annually). If, however, we also include emissions of Norwegian fossil sources *abroad*, the emissions increase from 41 Mt CO_2 annually, to 507 Mt.

In another recent study where CBA was involved, we looked into Chinas´ transport related CO_2 emissions (Cui et al. 2023). Globally, the transport sector accounts for 20 % of the total GHG emissions globally, and some 90 % of nature loss, and 50 % of global GHG emissions is related to production, transport and consumption of goods according to a WWF-report release before the Montreal meeting on nature conservation. Our study revealed thar only 8 % of Chinas enormous transport-related GHG emissions is for the domestic marked, the rest is for export to other nations, among them Norway. China is by far the dominant nations when it comes to Norwegian import of consumables. Given the increased internet-based commerce, and that IEA predicts of up to 80% increase in road transport by 2050, it is time to reconsider the Norwegian contribution to global warming and nature loss.

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Picture: Fieldwork in Iskoras.
Credits: Jacqueline Knutson.

BioGov: Biogeochemical processes governing boreal C cycling

Dag Olav Hessen
Professor, Department of Biology

BioGov is a large (25 mill NOK) "fellesløftet project", cofounded by the Resarch Council of Norway and UiO, granted to CBA in 2022. It will represent a core activity for CBA in the years to come (until 2027). Biogov focuses on the boreal biome, including southern, alpine and permafrost regions of Norway. Here we will obtain parameterizations of the changes in boreal C stores (organic matter pools) due to alteration to ecosystem metabolism. These metabolic changes are direct or indirect results of (i) growing forest biomass, (ii) warming and changes in precipitation, and (iii) the activation of huge stores of organic C through thawing of permafrost. These changes in flux and fates of C-stores are prone to boost emissions of greenhouse gases (GHG) and volatile organic compounds, as well as transport of dissolved organic matter from land into lakes, rivers, and coastal areas. In particular boreal lakes are globally significant sources of CO_2 and CH^4 to the atmosphere by microbial conversion of organic matter originating from the terrestrial part of the catchment.

The biogeochemical mechanisms governing NOM quality and lateral fluxes, as well as its subsequent microbial transformation into GHGs in lakes and rivers, are poorly understood and constrained in models. Climate feedbacks might be overlooked or exaggerated without an in-depth understanding of how ecosystem metabolism varies over terrestrial landscapes and how metabolic process are intertwined. This understanding is currently fragmentary, causing uncertainties in climate predictions and thereby ineffective climate mitigation. Moreover, soil carbon modules of ESMs cannot be improved without high-quality data on decomposition rates and pool sizes.

Biogov will advance the current 1-D representation in LSMs by investigating the linkages with lateral fluxes, from micro- to regional scale, between decomposition of SOM, lateral transport of NOM, and vertical flux of GHG at three sites, in combination with laboratory experiments and synoptic water chemistry studies, thereby covering the Norwegian boreal ecosystem gradient. It consists of 5 integrated work packages (Fig. 1). Despite their importance, the processes governing lateral and vertical C fluxes are currently poorly represented in ESMs. This is mainly due to the small-scale variation in soil bio-physicochemical factors governing the fluxes, size distribution, photo- and bio- degradability of NOM on its way from mobilization in soils, transport through soil water flow-paths, until entering rivers and coast.

During 2022 4 PhD were hired, the first start-up meeting was held, but the full range of fieldwork, experiments and modelling will begin in 2023.

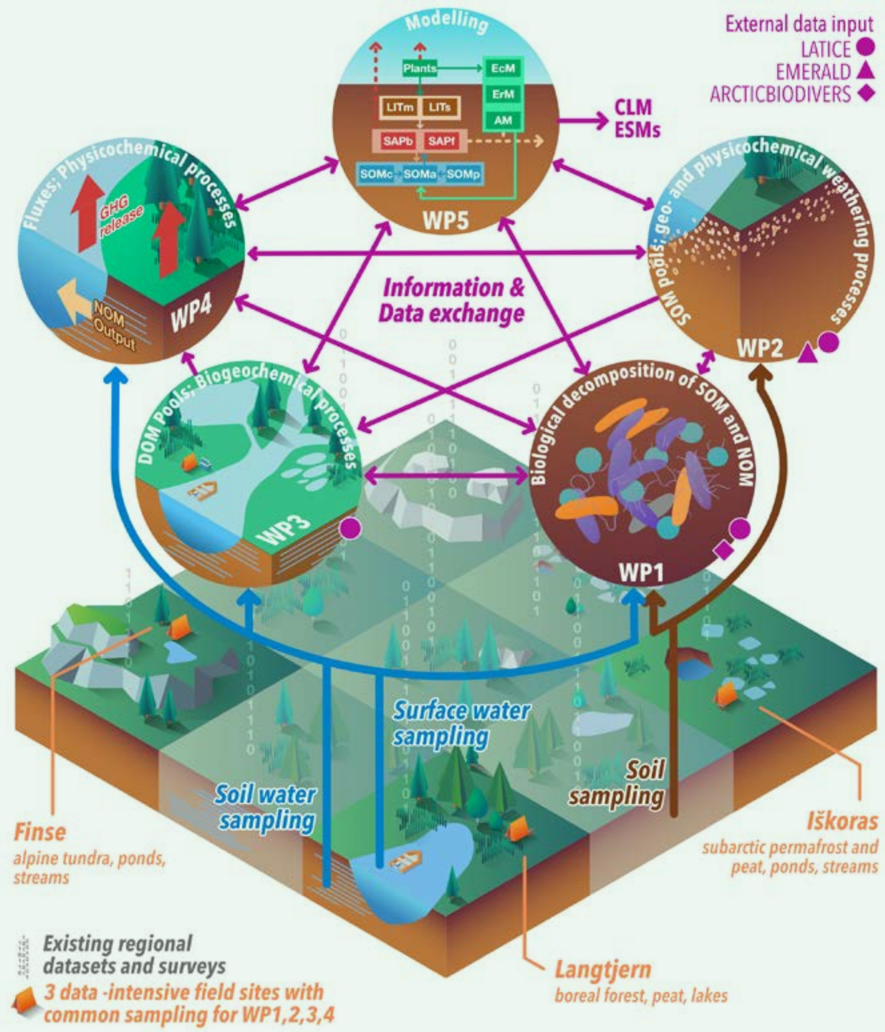

Figure 1: Project graphical abstract with WP tasks and deliverables. The project has a tightly integrated field and laboratory part that both aims at understanding basic coupling between physicochemical and biotic (microbial) responses as well as input for parameterization and optimization of predictive models. Finally, this will be important inputs to more general models like NorESM.

Forecasting organic carbon concentration in boreal lakes in 2100

Camille Crapart
PhD student, Department of chemistry

In the Nordic countries, a widespread browning of surface waters has been recorded since the 1980s. It is due to an increase of organic matter and iron concentration, following the reduction of acid deposition, which increases the solubility of organic matter. In addition, catchment processes play a major role in explaining this browning. Climate and land-use changes also contributed to an increased flux of total organic carbon (TOC) from catchments to water bodies. Warmer temperatures lead to a longer growing season and more biomass production on the catchment, increasing the carbon pool in soils and the potential leaching towards rivers and lakes. Progressive abandon of outfield grazing and voluntarist policies in afforestation and forest management participated in the phenomenon.

In an article published at the beginning of 2023, we assessed the major governing factors for increased TOC levels among several catchment characteristics in almost 5000 Fennoscandian lakes and catchments. We identified the proportion of biomass (estimated by the Normalized Difference Vegetation Index, NDVI), peatland and arable land, as well as the surface runoff and the nitrogen deposition, as the main predictors. Then, we calculated the theoretical effect that an increase of 1% of each of the characteristics would have on the concentration of TOC in lakes, everything being equal otherwise.

We then used these results to simulate future TOC concentration in lakes in 2050 and 2100 in Fennoscandia, as well as the subsequent export of TOC towards coastal waters.

We followed the forecasts of climatic variables in two of the Shared Socio-economic Pathways (SSP): 1-2.6 (+2 °C) and 3-7.0 (+4,5 °C). These scenarios yield contrasting effects. SSP 1-2.6 predicts an overall decrease of TOC export to coastal waters, while SSP 3-7.0 in contrast leads to an increase in TOC export. These changes are regionally contrasted. On the Norwegian west coast, a mountainous region, where the increase of surface runoff drives the changes in TOC concentration. In the south of Sweden and Finland, increases in temperature and biomass productivity and a slight decrease in runoff will result in two- to three-fold increases in TOC concentration. In both scenarios, northern regions will experience a drastic increases of TOC concentration.

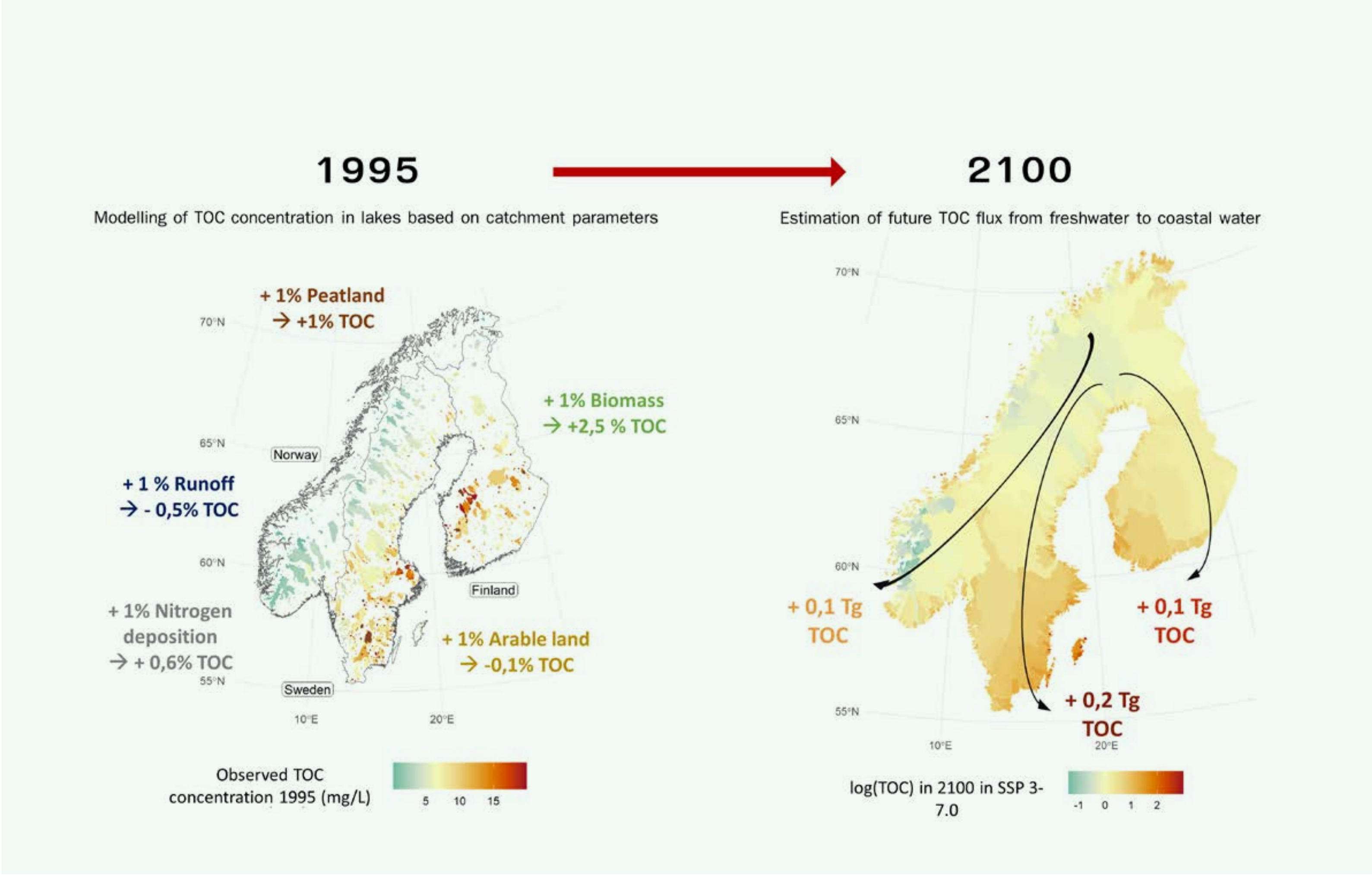

Figure 1: Increases in TOC consentration (%) and TOC export (Tg) in 2100, for the SSP 1-2.6 and SSP 3-7.0

+1% increase in:	Results in a TOC increase of:
Biomass (NDVI)	+ 3.2 %
Peatland	+ 0.9 %
Nitrogen deposition	+ 0.5 %
Arable land	+ 0.1 %
Surface runoff	- 0.3 %

Table 1: Theoretical increases in TOC concentration for a 1% change of the 5 main predictors

The browning of freshwater raises concerns about the resilience of boreal ecosystems: it impacts the light availability and the temperature in situ, impacting primary production and fishes' behaviour in lakes and in coastal waters. It also affects the quality of drinking water. Finally, changes in TOC fluxes can be reflected in greenhouse gases emissions from inland waters. Therefore, modelling these fluxes contributes to foreseeing the respective evolution of the related ecosystems, and potentially to adapt anthropic activities that impact them.

Source

Crapart, Camille, Anders G. Finstad, Dag O. Hessen, Rolf D. Vogt, and Tom Andersen. 2023. "Spatial Predictors and Temporal Forecast of Total Organic Carbon Levels in Boreal Lakes." *Science of The Total Environment* 870 (April): 161676. *https://doi.org/10.1016/J.SCITOTENV.2023.161676*

Evaluating global and regional land warming trends in the past decades with both MODIS and ERA5-Land land surface temperature data

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Highlights

- Decadal warming rates were analyzed in global, continental, and pixel scales.
- Land temperature from MODIS and from ERA5-Land were analyzed and found consistent.
- Continents were warming at substantially different rates in the past decades.
- Arctic permafrost areas were the fastest warming land on Earth during 2001–2020.
- ERA5-Land data reveal that warming was accelerating in the 40-yr period 1981–2020.

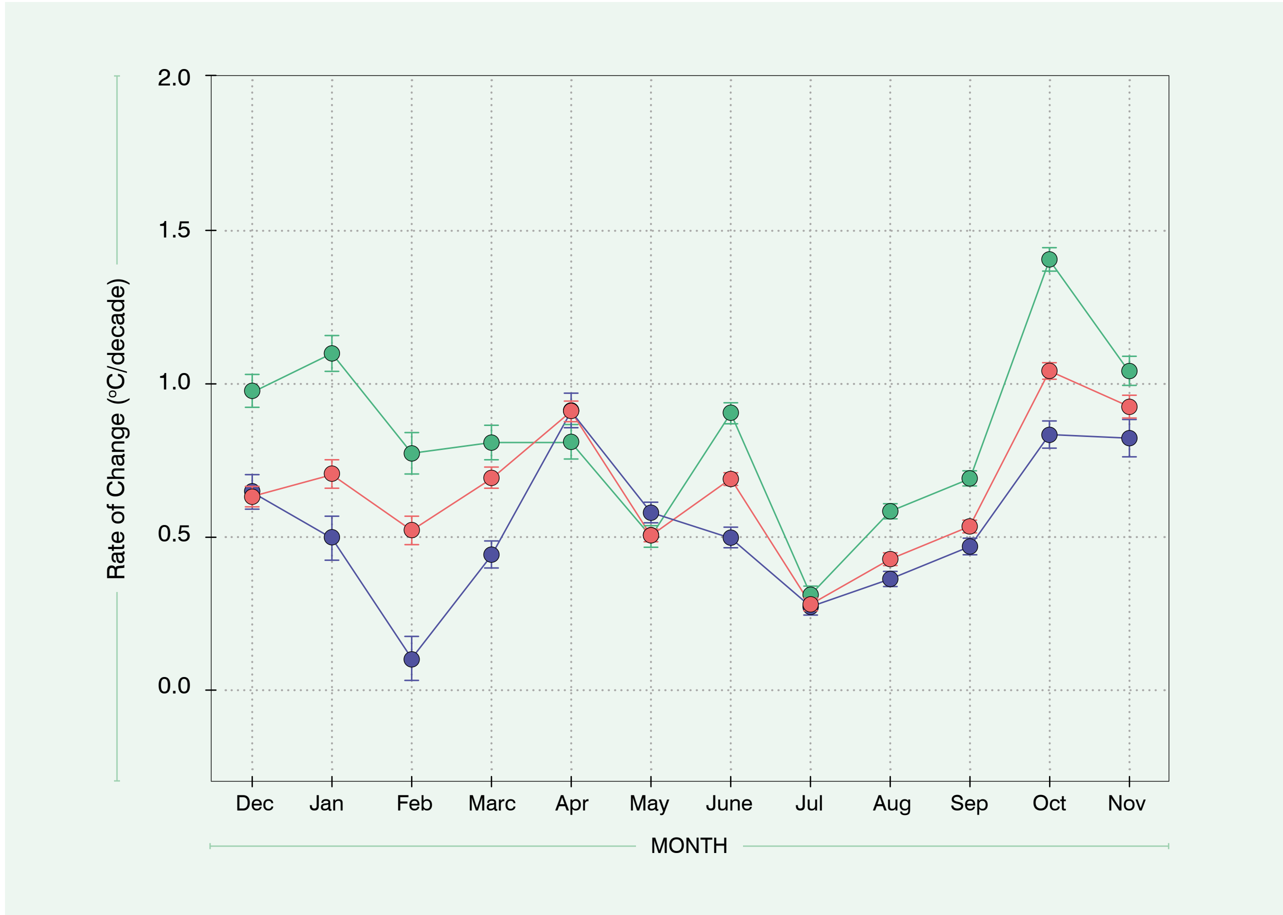

Figure 1: Temperature trends in the Arctic obtained by two 30-yr periods and one 40-yr period in ERA5-Land. Error bars indicate ±2 standard error for 95% confidence interval from the regression for the rate of change of each month.

ERA5-Land 1981–2010
ERA5-Land 1991–2020
ERA5-Land 1981–2010

Abstract

Global surface temperature has been setting new record highs in the recent decades, imposing increasing environmental challenges for societies and ecosystems worldwide.

Global warming rates of the 20th century have been documented by a number of studies, nevertheless, the warming rates in the most recent decades in the 21st century are of particular interest for understanding the ongoing climate change. Analyzing temperature trends demands data with high spatial resolution and broad geographical coverage to allow for analyzing trends and changes on a regional scale. Land Surface Temperature data from NASA MODIS with global resolution of 0.05 degree and Skin Temperature data from European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5-Land reanalysis with global resolution of 0.1 degree fulfill these demands.

In this study, we analyze the remote-sensing-based MODIS data to estimate land surface temperature change rates over the period 2001-2020 in global, continental, and pixel-wise scales with statistical significance indicated. The model-based ERA5-Land data are also analyzed in parallel, extending the period of analysis back to 1981. These two independently-sourced datasets, one from satellites above the atmosphere and one from combining surface modelling and observations, are shown to produce highly consistent results. It is revealed that the trends in the shorter period 2001–2020 are spatially conforming to the trends in the longer period 1981–2020 despite the shorter time length.

For the period 2001-2020, we show that the global average land surface

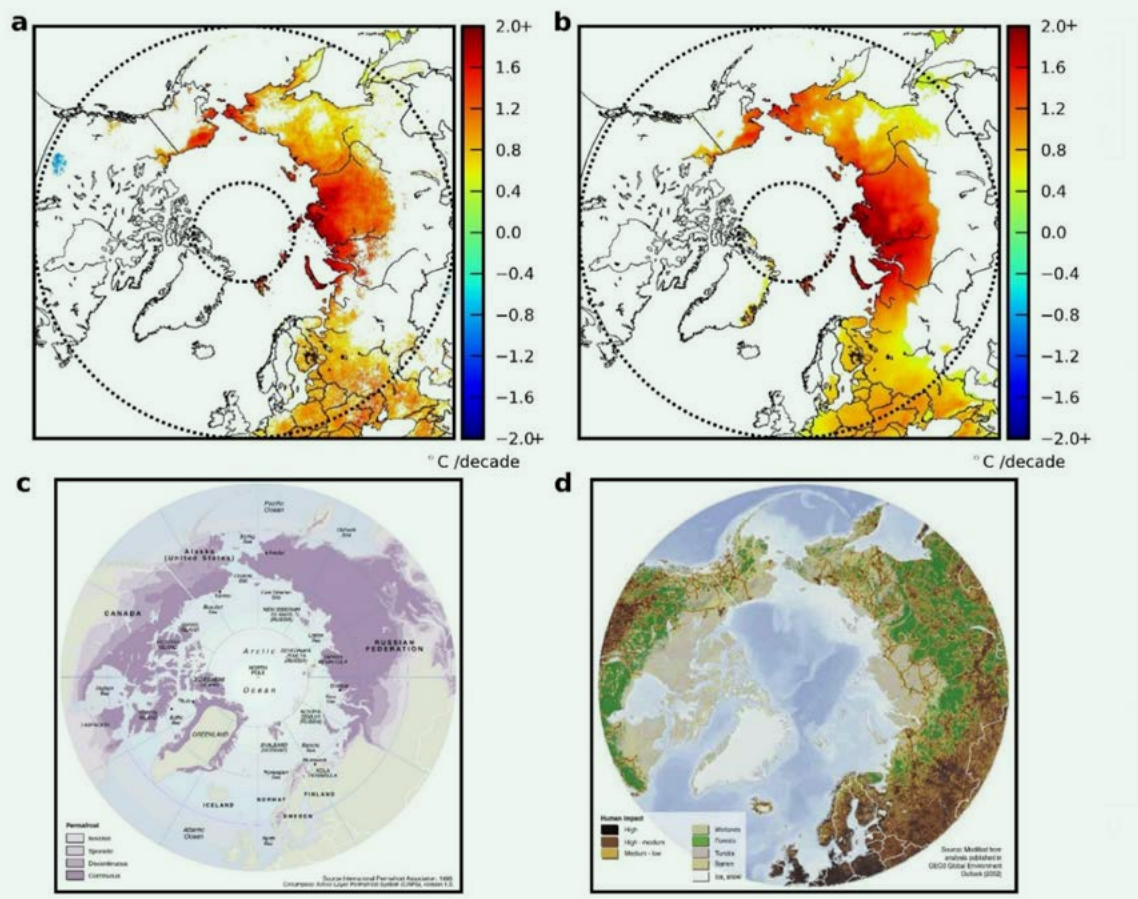

Figure 2: Areas with significant temperature rate of change, permafrost, and land cover in the circumpolar region. (a) From MODIS LST. (b) From ERA5-Land SKT. (c) Map of circumpolar permafrost areas made by UNEP/GRID-Arendal using data from International Permafrost Association (1998). (d) Map of land cover types made by UNEP/ GRID-Arendal using data from GEO3 Global Environment Outlook (2002).

temperature rate of change was 0.26°C-0.34°C per decade, with substantially different warming rates in different regions. The Arctic, Europe, and Russia show statistically significant warming in both datasets. The Arctic, in particular, warmed at a rate 2.5-2.8 times the global average, and data in the 40-year period 1981-2020 suggest that warming is accelerating in almost all the continents or large regions. Most noticeably, the two independent datasets both indicate that Arctic permafrost regions had the world's highest warming rate at the onset of the 21st century, reaching more than 2°C per decade in some areas.

Conclusions

Evaluating global and regional temperature rate of change for the 21st century is crucial in forming the scientific basis for the study of recent development of climate change. In this work, land surface temperature data from remote sensing-based MODIS and from model-based ERA5-Land were analyzed for the period 2001-2020, yielding consistent results. To explore beyond the limited 20-yr period, additional trend analyses were performed for data in the 40-yr period 1981-2020, which are available only with ERA5-Land. The results indicate that temperature trends obtained from the relatively short 20-yr period are conforming to the general trends in the 40-yr period.

Near the Northern treeline, Junjik River valley, Brooks Range, Alaska.
Credits: Sebastian Westermann.

Warming trends were examined in global, continental, and pixel scales with p-values for significance. Continents and large regions were found to be warming at substantially different rates, with the Arctic, Europe, and Russia being the fastest warming regions around the globe. In addition, with ERA5-Land data, comparison between temperature change rates of different time periods reveals that warming in the Arctic and in most of the continents is accelerating during the 40-yr period 1981–2020.

Geographically, the fastest warming land on Earth during 2001–2020 was found to coincide with the tundra biota in circumpolar regions in general. This suggests that the biota has been under rapid warming for decades, and the biological and climatic consequences are profound even if the warming can be due to internal climate variability on top of the GHG-forced climate change. Specifically, the rapid warming of the Arctic permafrost signals the acceleration of Arctic permafrost thaw and thus the deterioration of climate change in the onset of the 21st century.

"Arctic permafrost regions had the world's highest warming rate at the onset of the 21st century, reaching more than 2oC per decade in some areas"

Disentangling effects of natural and anthropogenic drivers on forest net ecosystem production

You-Ren Wang
Postdoctoral Fellow,
Department of Biosciences

Highlights

- Impacts of environmental drivers on forest CO_2 fluxes are often mixed.
- We analyzed 231 site-year forest data and 7 natural and anthropogenic driver data.
- We disentangled driver impacts on CO_2 fluxes by GAM regression analysis.
- Thresholds of S and N deposition for substantial impact on NEP were determined.
- We developed novel empirical models for estimating forest net CO_2 fluxes.

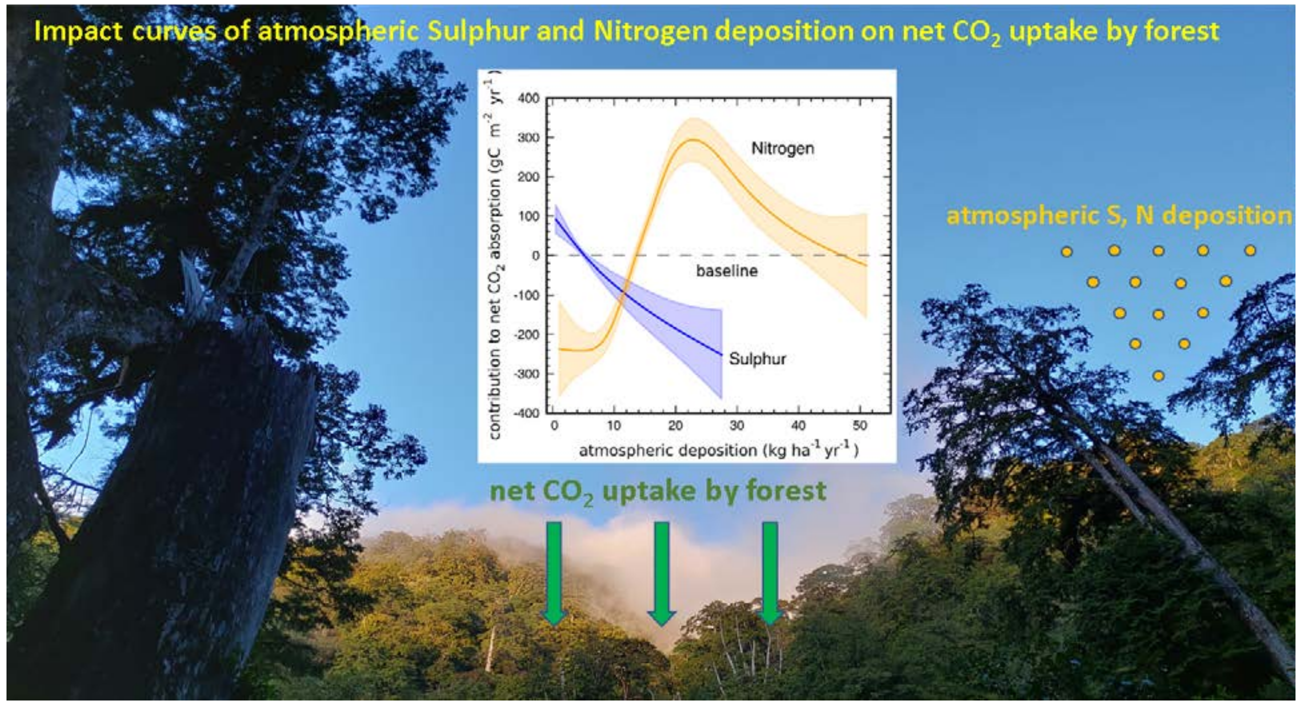

Figure 1: Impact curves of atmospheric Sulphur and Nitrogen deposition on net CO_2 uptake by forest.

Abstract

Net Ecosystem Production (NEP) of forests is the net carbon dioxide (CO_2) fluxes between land and the atmosphere due to forests' biogeochemical processes. NEP varies with natural drivers such as precipitation, air temperature, solar radiation, plant functional type (PFT), and soil texture, which affect the gross primary production and ecosystem respiration, and thus the net C sequestration.

It is also known that deposition of sulphur (S) and nitrogen (N) influences NEP in forest ecosystems. These drivers' respective, unique effects on NEP, however, are often difficult to be individually identified by conventional bivariate analysis. Here we show that by analyzing 22 forest sites with 231 site-year data acquired from FLUXNET database across Europe for the years 2000–2014, the individual, unique effects of these drivers on annual forest CO_2 fluxes can be disentangled using Generalized Additive Models (GAM) for nonlinear regression analysis. We show that S and N deposition have substantial impacts on NEP, where S deposition above 5 kg S ha^{-1} yr^{-1} can significantly reduce NEP, and N deposition around 22 kg N ha^{-1} yr^{-1} has the highest positive effect on NEP.

Our results suggest that air quality management of S and N is crucial for maintaining healthy biogeochemical functions of forests to mitigate climate change. Furthermore, the empirical models we developed for estimating NEP of forests can serve as a forest management tool in the context of climate change mitigation. Potential applications include the assessment of forest carbon fluxes in the REDD+ framework of the UNFCCC.

Conclusions

Our study reveals that while S deposition shows a clear impact to reduce NEP at elevated levels, the impact of excessively high N deposition is less clear. To prevent the loss of CO_2 uptake and to improve air quality and biodiversity, it is important that actions be taken to further control S and N depositions.

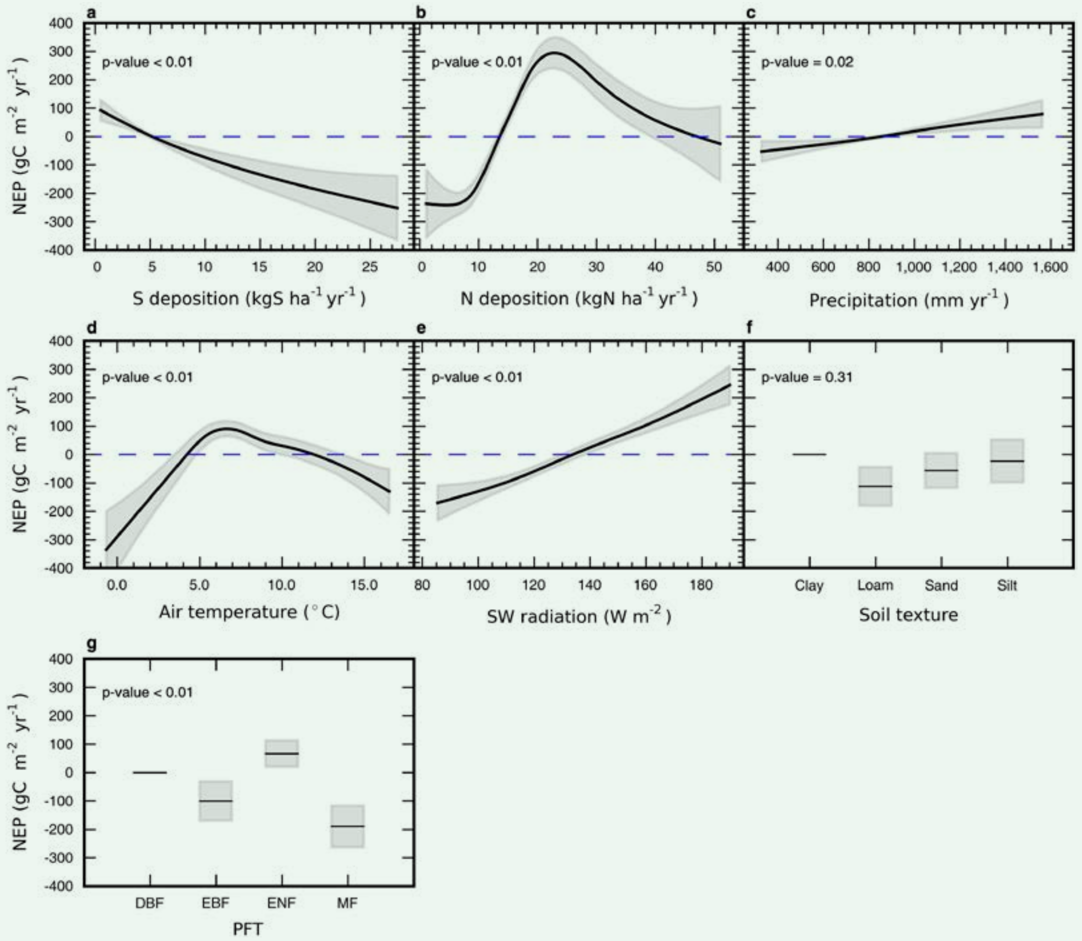

Figure 2: GAM regression analysis results for NEP partial dependence on the seven environmental drivers at all strength levels. The Y axis shows driver contributions to NEP relative to the modelled baseline. Contributions from (a) S deposition; (b) N deposition; (c) precipitation; (d) air temperature; (e) incoming shortwave radiation; (f) soil texture; and (g) PFT. All the gray bands show 1σ uncertainty. The modelled baseline NEP level is 478.0 gC m-2 yr-1. Except for soil texture, the p-values of the other six drivers are all below 0.05, showing statistical significance in impacting NEP.

Potential mitigation measures include, but are not limited to, the review of the policy for coal-fired power plants, vehicles using fossil fuels, fertilizer use, and agricultural production, to echo the appeal in the Paris Agreement that "Parties should take action to conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases as referred to in Article 4, paragraph 1(d), of the Convention, including forests".

There have been various attempts on estimating forest CO_2 fluxes in recent years, globally or regionally. It is particularly noticeable that in those forest CO_2-predicting models, including the bookkeeping, DGVM, Ecosystem Demography, CBM, and EFISCEN models, the effect of S deposition is not considered. This may cause an underestimation of the detrimental effects of air pollution and thus an overestimation of forest NEP, depending on the level of S deposition.

In parallel with these recent attempts, the empirical NEP, GPP and RECO models that we developed in this work provide a convenient way for estimating forest CO_2 fluxes with seven drivers considered. Potential applications of these models include the assessment of carbon fluxes for REDD+. REDD+ is a framework created by the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP) to guide activities in the forest sector that Reduces Emissions from Deforestation and forest Degradation, as well as the sustainable management of forests and the conservation and enhancement of forest carbon stocks in developing countries. Central to the REDD+ framework is the forest carbon accounting, which requires a monitoring, reporting and verifying (MRV) system that tracks changes in forest carbon stocks. Therefore, establishing functional MRV systems is one of the major goals of the so called 'REDD Readiness'. Failure to account for net ecosystem carbon balance in REDD+ activities will lead to large uncertainty in estimating carbon emissions by forested landscapes.

As the current MRV methodologies mainly rely on forest inventory and remote sensing approaches, which primarily determine aboveground net primary production, there is a lack of information of carbon losses due to ecosystem respiration from soil and belowground carbon. Our empirical models for NEP, GPP, and RECO assessments, potentially, can fill the gap in REDD+ carbon accounting.

"To prevent the loss of CO_2 uptake and to improve air quality and biodiversity, it is important that actions be taken to further control sulfur and nitrogen depositions"

Tree-line expansion – A threat to hydropower resources? TREX-HYDRO. New project starting 2023.

Terje Koren Berntsen
professor Department of Geosciences

The UN has established 17 sustainable development goals (SDGs). IPCC has evaluated the potential synergies and trade-offs between the sectoral portfolio of climate change mitigation options and the Sustainable Development Goals (SDGs) (IPCC, 2018, cf. figure 4 SPM). SDG 7, Affordable and clean energy, was identified as the single SDG with the strongest synergies and with only minor unwanted trade-offs. With the need for more renewable energy sources to reduce greenhouse gas emissions and improve energy security, it is important to improve our understanding of how the water resources for hydropower can be affected by climate change and land use change.

The long term water balance of the land surface is governed by the balance between the input through precipitation and the loss through evapotranspiration and runoff. Over the recent decades we have got more robust estimates of regional changes in precipitation, which is also now being reproduced with global climate models (IPCC, 2021). The latter is a breakthrough since these regional differences are much more pronounced (and bi-directional) than for temperatures.

Until now, the main focus in relation to hydropower has been on the source of water through precipitation, which in many regions (and in particular in Norway) is believed to increase under climate change (Hanssen-Bauer et al., 2017). However, a significant amount of water is lost before it reaches the hydropower reservoirs through evapotranspiration (ET). Recent studies using models and in situ measurements (Liahjell, 2022; Nicholls and Carey, 2021) have shown that ET is enhanced when vegetation change from shrubs to forests (figure 1). Preliminary results (Liahjell, 2022) indicates that the reduction in runoff for the mountainous regions of southern Norway (cf. figure 2) could be as high as 15% due to the rise in tree-lines since the late 19th century.

In Norway, the observed increase in precipitation over the recent decades has only partly been matched by a similar increase in runoff (Hanssen-Bauer et al., 2017). As water storage is believed to have decreased (through glacier melt) rather than increased during this period, it seems likely that more water is being lost through evapotranspiration, in response to the increase in vegetation and temperature. However, the underlying causes for this is complex, as the response of ET to climate change is not merely a function of temperature and includes several non-linear components. First, direct evaporation depends on both available energy, atmospheric turbulence, air humidity, the presence of surface water bodies, canopy water, soil and groundwater. Secondly, the transpiration component depends both on biological factors (type and amount of vegetation) and on physical factors, such as photosynthetically active radiation, soil water, CO2 concentration. Land cover has changed substantially in Norway in response both to climate change (resulting in elevated tree and forest line), reduced grazing (leading to afforestation) and forest management (cf. figure 1 and 2).

In a new project (TREX-HYDRO) starting in 2023 the objective is to provide a robust estimate of how ET and runoff will change due to advancing tree-lines caused by climate and land use change, and how this will affect hydropower potential in the boreal regions. The project will use ecological distribution models to project vegetation changes, a regional climate model (WRF with the land module CLM-FATES) which includes dynamical vegetation, and finally advanced measurement technics established in the LATICE and Spot-On projects to validate ET estimates (Pirk et al., 2022). The project is a collaboration between UiO and the Natural History Museum.

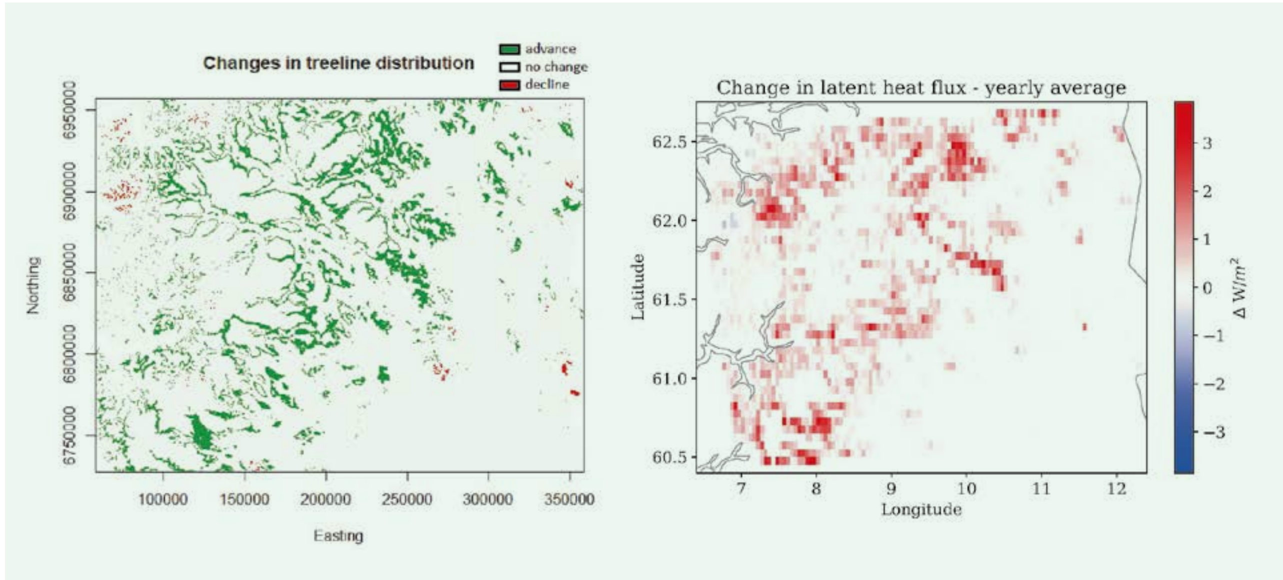

Figure 1: Newly established birch trees growing through a patch of salix shrubs at 1200 meter altitude in southern Norway. In the background the Stolsvatnet hydropower reservoir (1090 masl.). Credits: Terje K. Berntsen.

Figure 2: Estimated change in tree-lines since early 20th century (Naas, 2021). Corresponding simulated change in latent heat flux from the surface to the atmosphere (Liahjell, 2022). 1 Wm-2 increase in the latent heat flux corresponds to an increase in ET of 14 mm/yr.

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Photo: Getty Images

Research

What DNA can tell us about greenhouse gas emission

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Microbial regulation of greenhouse gas emissions

Thawing permafrost due to climate change is known to release previously frozen organic matter as methane and carbon dioxide into the atmosphere. However, less known is the role that microbes play in these greenhouse gas emissions. Microbes inhabiting permafrost peat use carbon as an energy source, and these peats are rich in biodegradable carbon. In their hunt for energy, microbes can degrade carbon into CO_2 and methane, but they can also consume these very potent greenhouse gases. Which of these processes are active depend on the microbial community present, and the environmental conditions surrounding them. In this way, microbes act as important regulators of GHG concentrations in their surrounding environment.

Changing permafrost landscapes

Far up north, close to the Finish border in Norway, we find Iškoras. This is one of few places in Norway with permafrost. The permafrost landscape here is to a large extent dominated by palsas and thermokarst ponds. The palsas, consisting of a mineral core covered with a permanently frozen peat layer beneath the non-frozen "active" peat, are protruding in the otherwise flat mirelandscape.

Picture: Permafrost samples were collected from a discontinuous permafrost area in Iškoras, Finnmark, Northern Norway (69°20'27" N, 25°17'44" E). A square hole (around 1m2) was dug on the surface. The active layer (0–0.6m from the surface) was put aside when permafrost cores (0.6–1.67m) were taken with a steel pipe (30mm inner diameter). Credits: Jing Wei.

"In their hunt for energy, microbes can degrade carbon into CO_2 and methane, but they can also consume these very potent greenhouse gases."

Scattered around the palsas are ponds, acting as time witnesses of the disappearing permafrost. When the permafrost thaws, the hard cores stabilizing the mounds disappear, leading to a collapse of previously frozen peat forming indents in the mire landscape. These pits will gradually be filled with water, creating thermokarst ponds. Once the ponds are formed, remaining palsas may fall into the ponds, leaving the previously frozen peat submerged. The microbial community inhabiting the now thawing peat may in this scenario experience changes in redox potential in the environment according to the redox tower, that is – they will experience a shift from an aerobic environment towards more anoxic surroundings. But how will such a shift in redox potential affect the GHG production and consumption in the thawing permafrost?

Role of redox

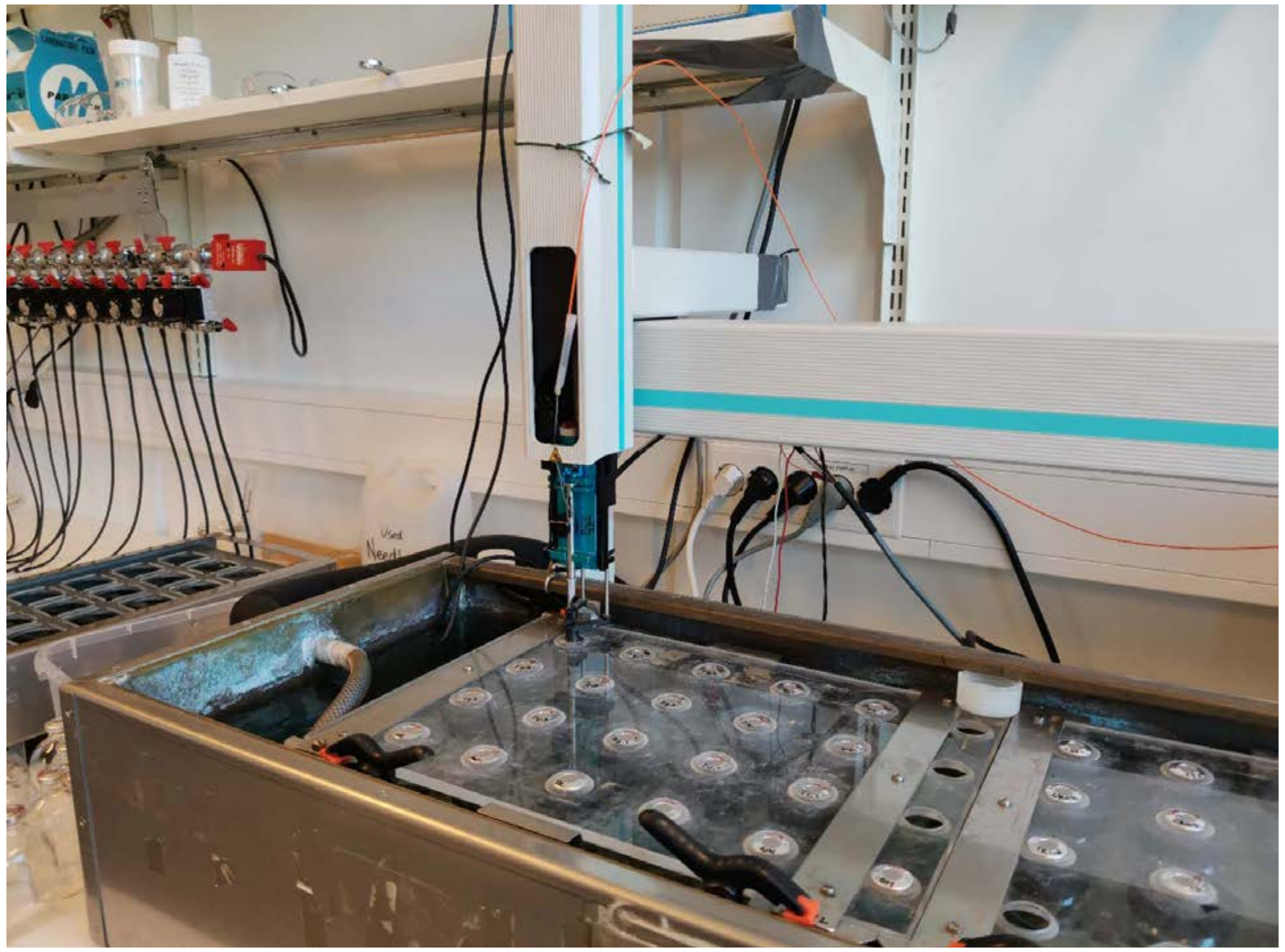
Central to the fate of the biodegraded carbon are the redox conditions surrounding the microbes. Redox conditions are tightly linked with redox reactions, which are important to basic functions of life, such as the metabolism of microbes. Both the rate and extent of biodegradation is affected by the redox conditions. For instance, for many organic compounds the degradation rates are higher in aerobic than anaerobic conditions. The final product of the biodegradation also depends on the redox conditions. In aerobic conditions, microbial heterotrophic respiration uses O_2 to alter carbon rich glucose into inorganic C in the form of CO_2. Biological production of methane, on the other hand, is facilitated through methanogenesis, a type of anaerobic respiration, where CO_2 is reduced to methane. Redox conditions may therefore be an important determining factor for both which GHG the microbes produce, and to what extent.

The wonders of metagenomics

By peeking into the genomes in microbial communities we can discover their functional potential – that is, which genes are present, to what extent, and in which metabolic pathways are they involved, or simply: what can the microbes do? Through metagenomic tools applied on DNA sequences from the microbes, we can focus our analysis on known carbon processing genes, such as those involved in heterotrophic respiration and methanogenesis, and in this way understand how microbial carbon processing is affected by environmental conditions.

The experiment

To understand the effects of redox conditions on GHG emission in thawing permafrost, Wei and coworkers conducted an incubation experiment where thawing permafrost cores were incubated under different redox conditions, simulated by different concentrations of oxygen. In this way, we were able to mimic redox gradients like those thawing permafrost may experience as palsas collapse and become submerged in thermokarst ponds. The carbon processing rates were measured as methane and CO_2 concentrations throughout the duration of the experiment. After the incubation period ended, DNA was extracted for metagenomic analysis. The metagenomic analysis allows us to reveal the metabolic pathways present, and their relative abundance, which can further be linked with the measured concentrations and production rates of GHGs under different concentrations of oxygen. The knowledge of which metabolic processes are being favored by microorganisms under different redox conditions will improve our understanding of future GHG emissions under climate forcing.



The incubation experiment was conducted in an automated incubator with a temperature-controlled water bath at 10°C. Headspace gas was sampled by a robotic arm of an autosampler and measured with a gas chromatograph in the laboratory of the Faculty of Environmental Sciences and Natural Resource Management, Norwegian University of Life Sciences, NMBU, Ås, Norway. Credits: Jing Wei.

The main questions we address in this experiment are:

1. How will redox conditions affect GHG emission rates of thawing permafrost?
2. How will redox conditions affect microbial functional community assembly in thawing permafrost, measured through biodegradation of C into CO_2 and methane?
3. Which microbial metabolic pathways are most associated with the measured GHG emission rates under changing redox conditions?

Waiting for the Tipping Point: The People vs. The Climate

Christina Nadeau
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In the year 1992, the IPCC published its first report which concluded that human activities were causing changes to the Earth's climate system, with the burning of fossil fuels being the main contributor. More than 3 decades, 6 IPCC report cycles, and 1.1°C of anthropogenic warming later, the core of the scientific message remains much the same, but the urgency this message carries has increased exponentially. The latest round of the IPCC assessment reports, AR6, published in 2021 and 2022 warn of a closing window of opportunity to reduce emissions and avoid a harrowing future, concluding that nations are not doing nearly enough to protect existing societies and future generations from the climate disasters. The impacts of climate change are happening much faster than previously expected, and AR6 warns of "tipping points" in the climate system that become more and more likely to be reached with ever degree of warming. This is probably familiar to researchers working in the natural sciences, yet it remains, to some degree, a point of contention amongst decision makers and the public.

The type of non-linear responses to climate change (or other stressors) in ecosystems have been described in many cases, some local, some regional. In essence it is the stage at which there is a systemic shift from one stable state to another, and where it is hard to "climb back" due to systemic constraints known as hysteresis. A tipping point may result from escalating feedbacks of the type that many CBA-activities focus on, and sudden changes like dieback of the Amazon, irreversible melting of glaciers, change in ocean circulation patterns, to some extent also permafrost thaw and others qualify as large-scale tipping points. What we must hope for is that societal tipping points in technology, economy, consumption and life style can counteract the risk of tipping point in nature.

Even in my few short years studying the concept of "tipping points" in my PhD project, I have observed the conversation around climate tipping points develop greatly both in the scientific community and beyond. My research covers the history of climate tipping points in scientific literature, beginning with articles in which climate tipping

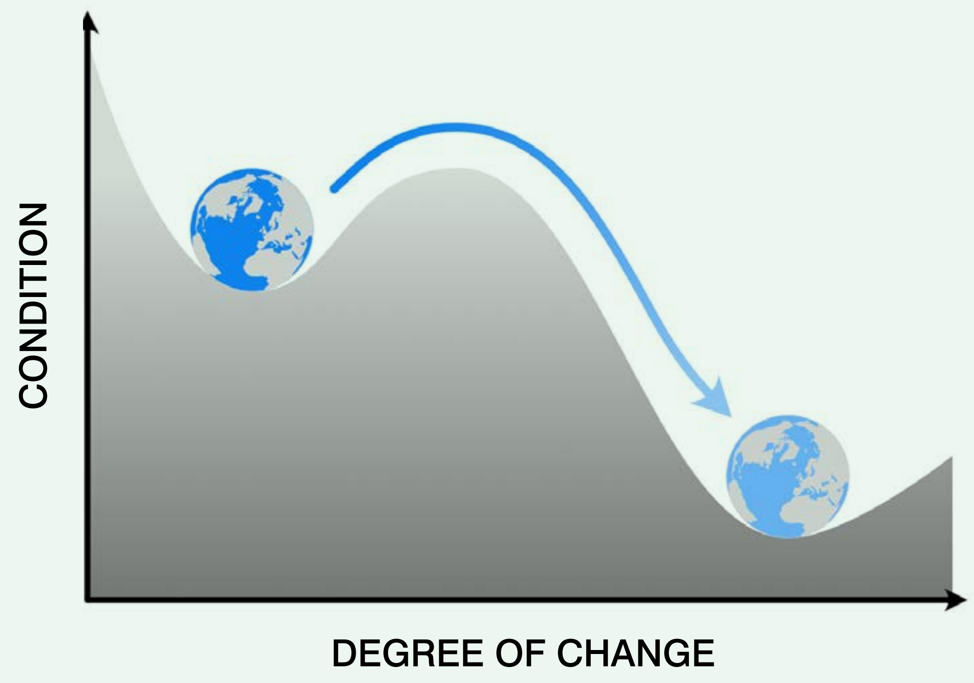

Figure: The concept of tipping point.
Credits: Jan David Heuschle.

points were presented as low risk high impact events. However, the most recent report reviewing our current state of knowledge of climate tipping points was published in September 2022, in which it was concluded that not only are climate tipping points now considered high risk events, but that some climate tipping points are already possible at 1 degree of warming. Only a week after this report was published, I attended a conference hosted by the University of Exeter dedicated solely to Tipping Points Research, the headline message of the conference stating clearly: "we have left it too late to tackle climate change incrementally, it now requires transformational change, and a dramatic acceleration of progress". After 3 days of worst-case scenario climate science and exploring transformative pathways of mitigative action, I left the conference with renewed vigour to continue my research in Norway, ready to launch my survey investigating the state of knowledge and level of concern for non-linear climate change amongst the Norwegian public.

Through this research on public perceptions of climate change, it has become obvious that Norway is a unique setting for my project. Multiple research studies over the last few years have uncovered Norway as the nation with the highest prevalence of climate scepticism in Europe. This information may surprise some and not others, but the reason for this result remains unclear. However, this highlights many reasons for why radical action has yet to be taken to slow carbon emissions. Climate change is complex, multifaceted, and interlinked with numerous other social, economic, and environmental issues. There is no one single solution that can effectively address all the challenges posed by climate change, yet the decisions we make today will have profound impacts on future generations. AR6 not only outlines dangerous climate tipping point in the Earth system, but the need to behaviour changes and social tipping points needed for transformative change, and it is this intersection in which my research lies. Are the public ready to accept large scale system change within their lifetime in order to lessen the future impacts of dangerous climate breakdown on future generations? We are told there is still time, however in 2022, emissions from fossil fuel burning rose yet again to reach a new record high. The question remains: who will hit a tipping point first, the people, or the climate?

I look forward to sharing my results and continuing my research alongside my CBA colleagues into 2023.

VOC measurements at a closed landfill by Proton-Transfer-Reaction Mass Spectrometry (PTR-MS) using a mobile laboratory

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&

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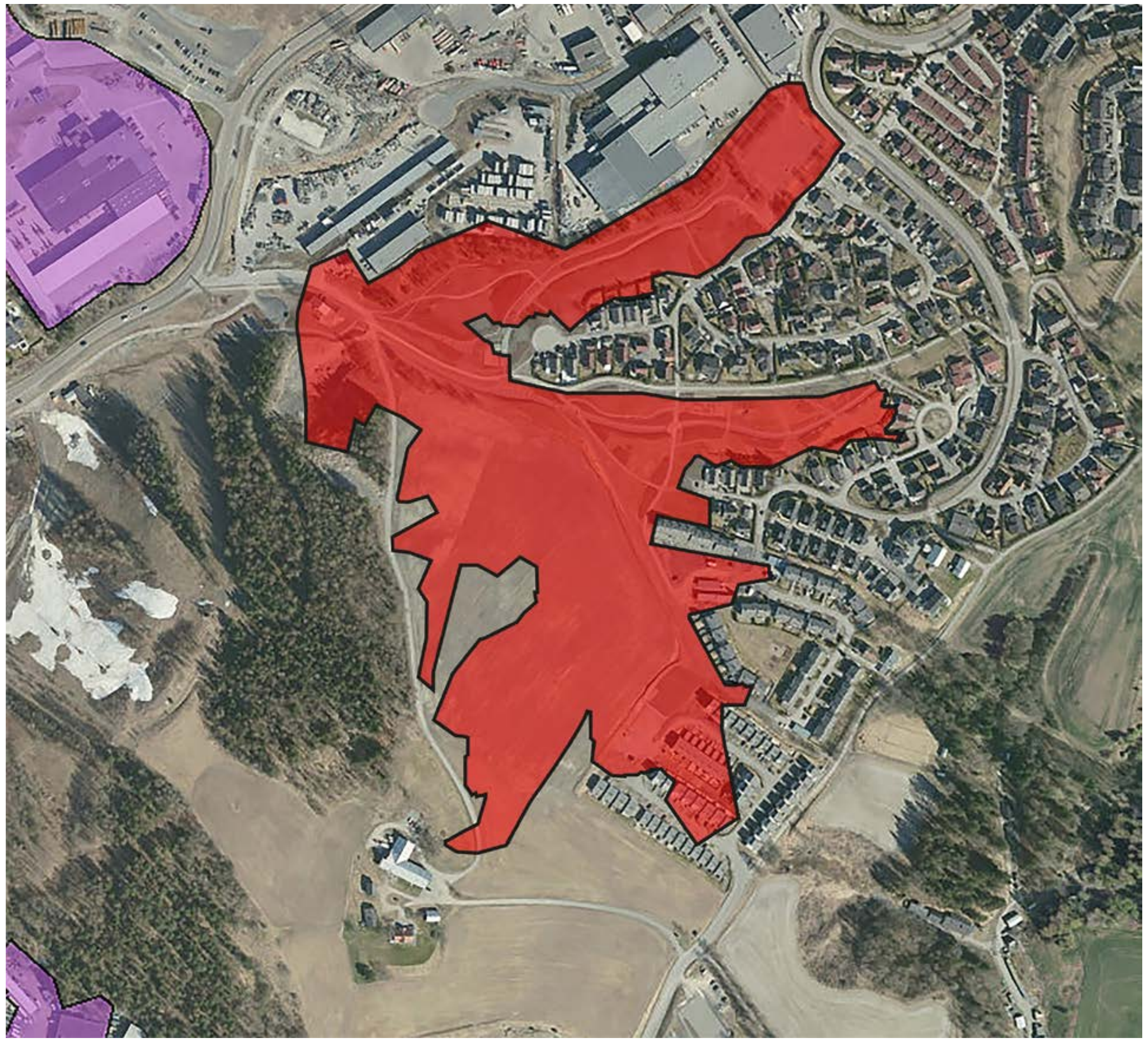
Emission of gases from landfills constitutes a growing issue in the context of global anthropogenic emissions.

Landfill gas primarily consists of 50–60 % CH_4 and 40 – 50 % CO_2.[1] Alongside these major components, roughly 1 % of landfill gas is made up of a mixture of gases present in lower concentrations referred to as trace gases. The term 'trace gases' predominantly refers to volatile organic compounds (VOCs) but may also include some inorganic compounds such as NH_3 and H_2S.[1] In this research, we utilized a mobile laboratory equipped with a Proton-Transfer-Reaction Mass Spectrometer (PTR-MS) to investigate the VOCs emitted from *Brånåsdalen nedlagte avfallsdeponi* (BNA), a closed landfill located in Lillestrøm, Norway.

BNA was operational from 1970–1990/1991. The deposited waste consisted of municipal solid waste, industrial waste, chemical waste and sewage sludge, however the exact composition of the waste is unknown. In 2010, inhabitants of houses surrounding BNA raised concerns about emissions from the landfill. Investigations revealed significant methane leaks into houses,

Mobile laboratory set-up showing the PTR-MS instrument in the trunk of the car. Credits: Alexander Håland.



Map of study site showing the area of Brånåsdalen landfill in red.
Screenshot from Grunnforurensning by Miljødirektoratet.

Set-up for sampling landfill gas from one of the vents coming out of the landfill. Credits: Silje Solevåg.

which resulted in one house being demolished and 22 ruled inhabitable.[2] Based on the history of the site, BNA makes an interesting and valuable study site for investigating the composition of trace gases in landfill gas.

An important part of the research was the use and validation of our mobile laboratory – a PTR-MS instrument installed inside of a car. This allowed for *in-situ* mass spectrometry measurements sampled directly from the emission points, thereby circumventing many of the additional sources of error generated from conventional sample collection followed by *ex-situ* measurements. To compare the results from the mobile laboratory to conventional sampling we also collected selected samples in a canister and analyzed them *ex-situ* by PTR-MS. Landfill gas was sampled from three vents connected to the underground gas collection system on seven days in the time period November – December 2022.

Although the data analysis is still underway, our preliminary findings indicate clear enhancements of VOC signals in the PTR-MS spectra of landfill gas compared to the ambient air. We have identified signals that correspond to compounds reported to be present in landfill gas in previous studies, such as methanol, acetone, or dimethyl sulfide.[3,4,5] Furthermore, we found notable variation in which VOC signals that were observed and their intensity both between sampling sites and sampling days. Finally, the mobile laboratory was found to be highly useful as *ex-situ* sampling by canister was more prone to sampling error. Even so, the observed signals in PTR-MS spectra from canister sampling matched well with corresponding spectra from *in-situ* sampling.

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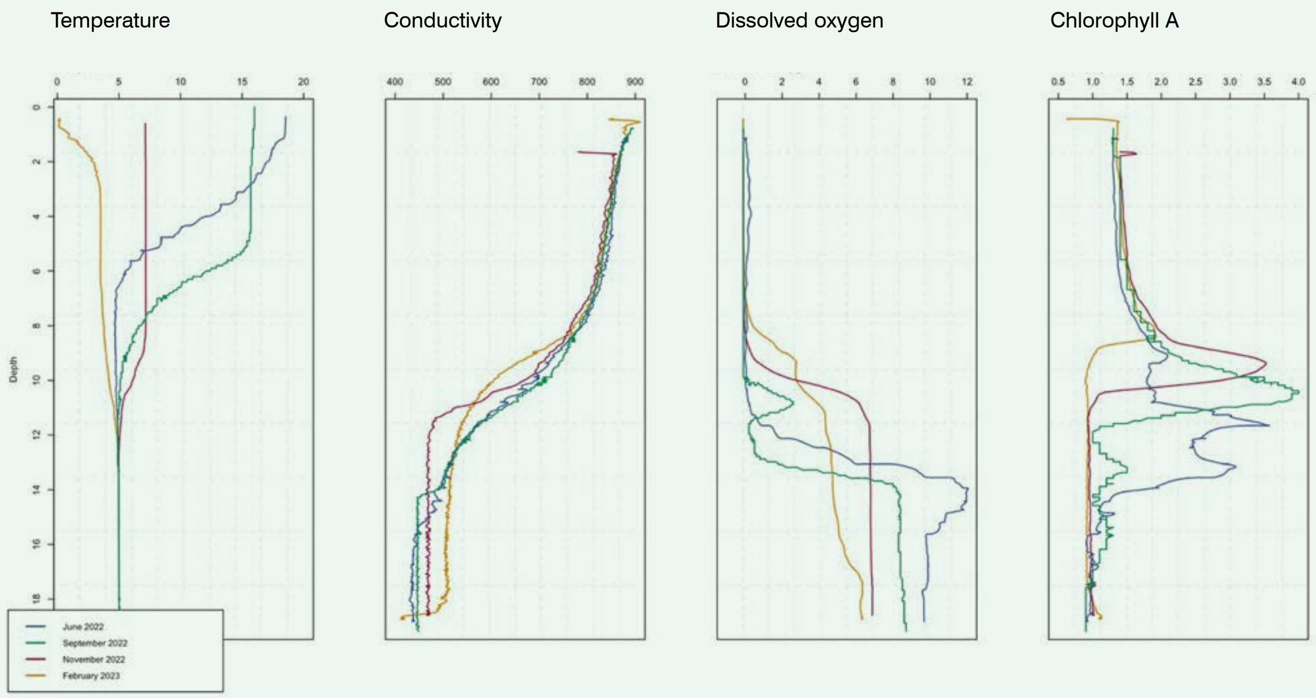
Meromictic lakes as hot spots for methane and CO_2

Christine Riis-Pedersen
Master student, Department of Biosciences

A study of 4 meromictic (never-mixing, permanently stratified lakes with salty deep-waters) reveal an intriguing biogeochemistry along the depth profile, and that such lakes are hot spot for greenhouse gas emissions. Climate change and extensive road salting in the catchment can promote these conditions. 4 master students address various aspects of these lakes by microbial studies (eDNA), lake chemistry, gas concentrations and production plus how this supplies also phyto- and zooplankton communities.

A meromictic lake has chemically different water that remains partly or wholly unmixed with the rest of the water mass during circulations. The lake's deep water is anoxic and called monimolimnion. This water is separated from the upper water, mixolimnion by the chemocline. The short water layer making up the chemocline has a steep gradient in chemical properties such as dissolved oxygen, density, and conductivity. Ion rich waters are heavier and thus accumulate in deep layers and cause resistance towards mixing. These layers become permanently anoxic, providing a vigorous production of CH_4 and CO_2. The studies lakes are naturally meromictic due to accumulation of various ions. Still, for some lakes the condition have worsened due to extensive road-salting within their catchments, and globally there are several examples of lakes with induced meromixis due to road salt. As most of the limnology focuses on holomictic lakes, which are by far the most common, meromictic lakes and their unique properties, remain understudied. Since the mixing regime of lakes may be affected by climate

Late season sampling.
Credits: Christine Riis-Pedersen.



Seasonal profiles for some parameters in one of the lakes.

Winter sampling at one of the meromictic lakes.
Credits: Dag O. Hessen.

"Since the mixing regime of lakes may be affected by climate change and anthropogenic effects like road salting, getting a greater understanding of meromictic lakes is increasingly important."

change and anthropogenic effects like road salting, getting a greater understanding of meromictic lakes is increasingly important. Biological processes could also contribute to the meromixis by the microbial production greenhouse gases from the chemocline and below. In certain meromictic lakes, like one of the studied lakes with iron-induced meromixis, the methane concentration is at a level that in principle could be exploited industrially. Levels above 150 000 ppm for methane are generally recorded in the deep, anoxic layers. The meromixis in another of the lakes is at least partially caused by the road salt from the highway just beside the lake. This lake also has an N_2O peak at the chemocline at several seasons.

My master project is affiliated with the large BioGov project at CBA. Four meromictic lakes outside Oslo, affected by road salt to a different extent, will be sampled seasonally. Gas samples using a headspace method, environmental DNA (eDNA), vertical profiles, and water to analyze for nutrients and cations will be collected. The data give insight into the microbial community composition and activity at different depths, water chemistry, and seasons. Where historical data exist, the results will be compared to historical data to see how anoxia have developed over the years and relate this to the potential runoff of salts that previously have been assessed in these lakes.

Another master projects look more into the gene expression of the microbial communities, and two other master projects look into how the chemical conditions and the dense microbial communities and the boundary layer between anoxic and oxygenated layers (the chemocline) interact with phytoplankton and zooplankton communities. Also, a guest researcher at CBA run incubations with sediment and water of the lakes to assess the rates of CH_4 and CO_2 production. Also, Armin Wisthalers group at the chemistry department supplement these studies by their mobile lab that analyse CH_4 in the atmosphere around these lakes.

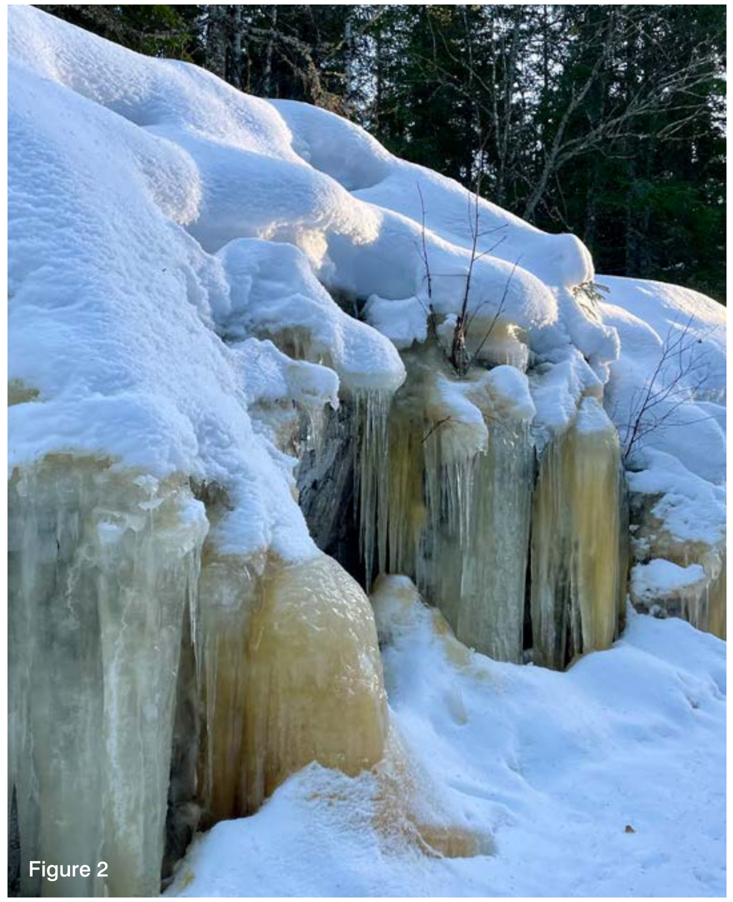
Together this can hopefully give better insights into the unique properties of such lakes and their role as hotspots for greenhouse gas production.

Coastal darkening: From Baltic forests to the Barents Sea

Dag Olav Hessen
Professor, Department of Biology

One of the trends that has received much attention over the past couple of decades is the phenomenon of "browning" (or "brownification"), notably in northern lakes and rivers. The proximate cause of this browning is increased concentrations of highly colored dissolved organic matter (DOM) originating from vegetation, soils and bogs, generally large, complex molecules known as humic acids (Fig. 1). The consequences of this browning are first and foremost increased light attenuation, lowering the depth of photosynthesis. Secondly the organic molecules, yet quite recalcitrant, also form substratum for heterotrophic bacteria. Together this drives aquatic systems to a larger degree of net heterotrophy; less uptake of O_2 and increased emissions of CO_2. These changes are not trivial in in a global climate change perspective either since northers freshwater are major conduits of terrestrially fixed carbon to the atmosphere. To this add that increased browning also promotes deep water anoxia and methane emissions.

The impacts are manifold and so are the drivers, yet more disputed. There is evidence that changes in land use, reduced acidification and climate (including changed hydrology) all may contribute substantially to browning. Also increased concentrations of iron (Fe), typically accompanying the organic carbon, add to this browning effect. Fe has strong chromophoric properties in itself with a strong absorption towards lower wavelengths and adds to the light attenuation caused by organic carbon. Sooner or later the brown freshwater reaches coastal areas, and while a significant fraction of the terrestrial C is lost (mostly oxidized by bacteria, some by solar photooxidation) on its way to sea, but also a significant portion remains. The question is then the fate of this DOM in the marine systems; is it flocculated and enters the sediments, is it diluted to nearly homeopathic and thus insignificant concentrations, or may it also pose relevant impacts on the marine recipient waters by increasing the light attenuation? There are also other impacts that affect coastal waters at high latitudes. Progressing permafrost thaw and glacier melt also promotes increased fluxes of dissolved and particulate matter of terrestrial origin to coastal areas with major impact on the underwater light regime, primary production and ecosystem processes (Fig. 2).



Humic acids: These cause a distinctive brownish color on many waterfalls in boreal areas (Figs. 1 and 2). Credits: Dag O. Hessen.

Forest planting and afforestation, notably of coniferous forests, are known to promote carbon export and thus browner or darker waters. The CBA-project *A green-blue link made browner: how terrestrial climate change affects marine ecology*, a cooperative NFR-project with University of Bergen, links increased forest volume, representing increased terrestrial net primary production, to ecosystem responses in distant, marine ecosystems. More specifically we relate an observed reduced transparency in Norwegian coastal waters over the past 100 years, where the causes are primarily ascribed the increased forest volume in the Baltic Sea catchment, and the effects are delayed blooming of phytoplankton along the Norwegian coast (Opdal et al. 2019; Opdal et al. 2023). Subsequently this also cause delayed copepod reproduction, thus explaining the delayed period in cod spawning observed over the past decades. This chain of events is a striking example on connectivity between distant ecosystems.

A related work by PhD-student Camille Crapart addressed the spatial and temporal drivers of DOM to surface waters of Fennoscandia, and also made predictions of current and future (2100) export of DOM to coastal waters, showing that low emission scenarios may cause reduced darkening, while vice versa for high emission scenarios (Crapart et al. 2023).

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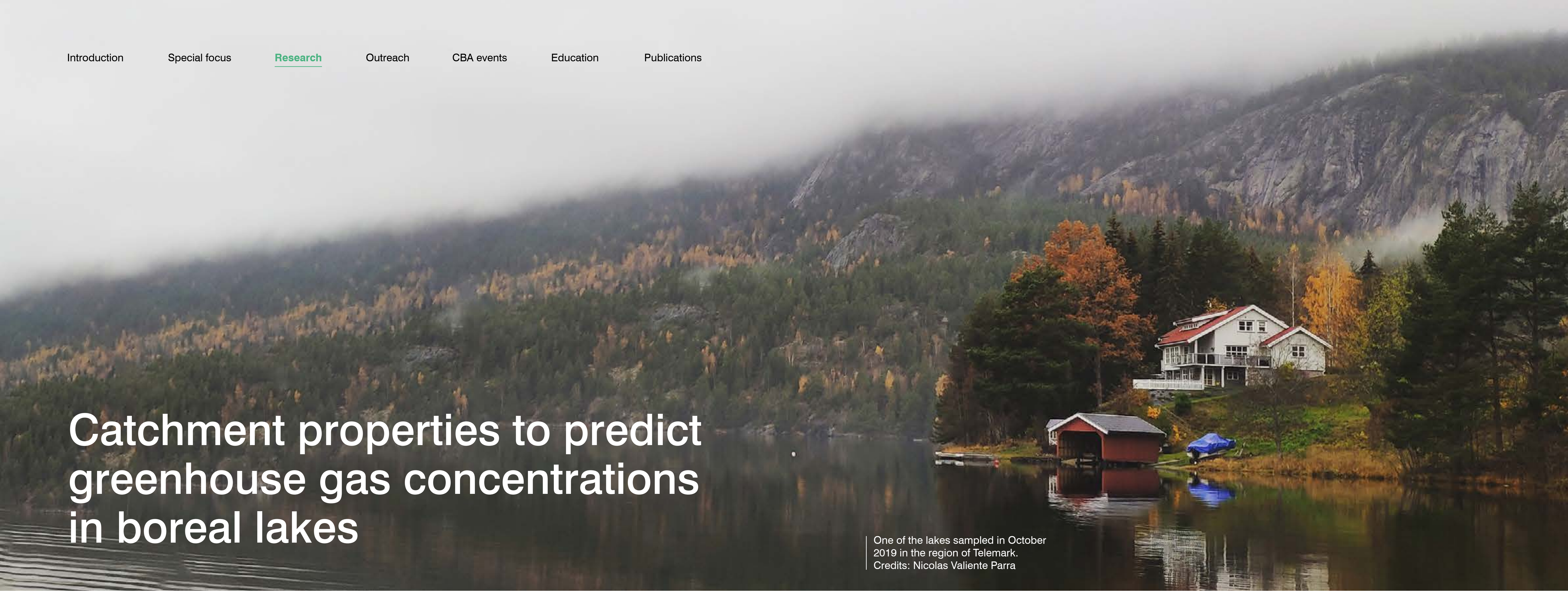

Catchment properties to predict greenhouse gas concentrations in boreal lakes

One of the lakes sampled in October 2019 in the region of Telemark.
Credits: Nicolas Valiente Parra

Nicolas Valiente Parra
Postdoctoral fellow,
Department of Biosciences

Boreal ecosystems are expected to be among the most affected biomes by climate change.

There, changing climate will result in increased precipitation and runoff (Tranvik et al., 2009), and recent studies showed that the proportion of forest cover in Fennoscandia has increased, leading to larger biomass pools. Concerning inland waters, boreal lakes are the most abundant lakes on Earth. These lakes receive high loading of allochthonous dissolved organic matter (DOM) from the catchment ("browning"). The increase in terrestrial biomass ("greening") has boosted the amount of allochthonous DOM that may be entering into surface waters, with increased rainfall and runoff further enhancing DOM catchment export. Moreover, browning strongly affects light attenuation, nutrient dynamics, and thus also primary productivity. Therefore, boreal lakes play a crucial biogeochemical role: on the one hand, they sequester DOM by burial into lake sediments, while on the other hand, they are generally net heterotrophic and act as major conduits for greenhouse gas (GHGs) emissions. The combined effect of increased DOM and increased light attenuation implies a decrease in photosynthesis, thus promoting the heterotrophy of these systems and the net emissions of GHGs derived from microbial mineralization of DOM (Allesson et al., 2021).

CBA researchers led a study on how browning affects the aqueous communities and ecosystem processes, boosting GHG emissions along a gradient of boreal lakes (Valiente et al., 2022).

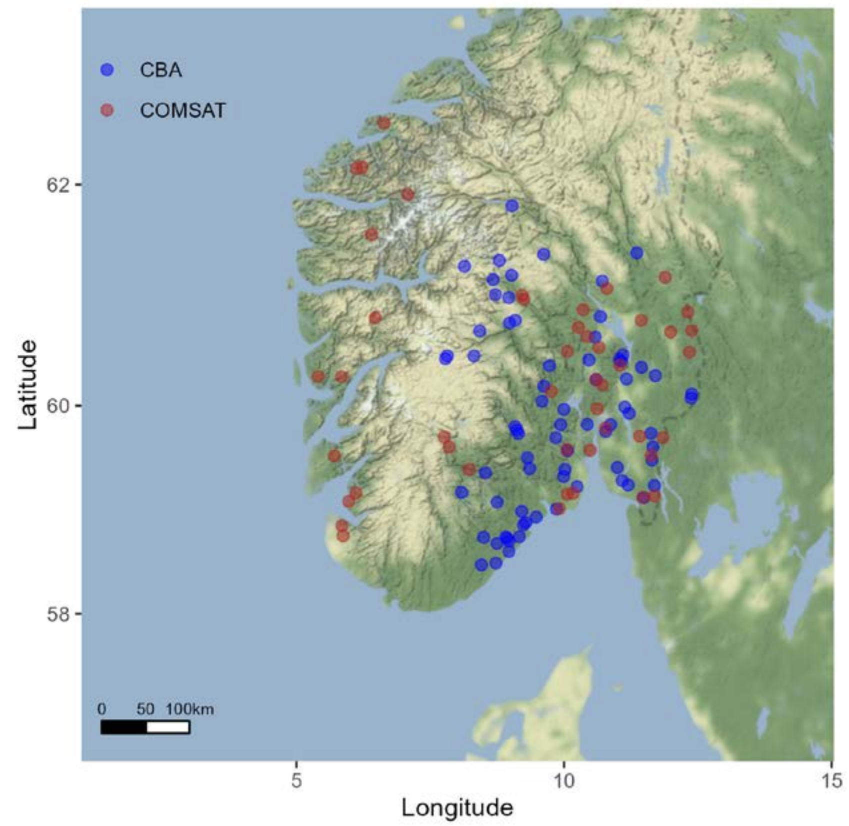

Figure 1:
Lakes included in CBA (n = 73) and COMSAT (n = 46) surveys.

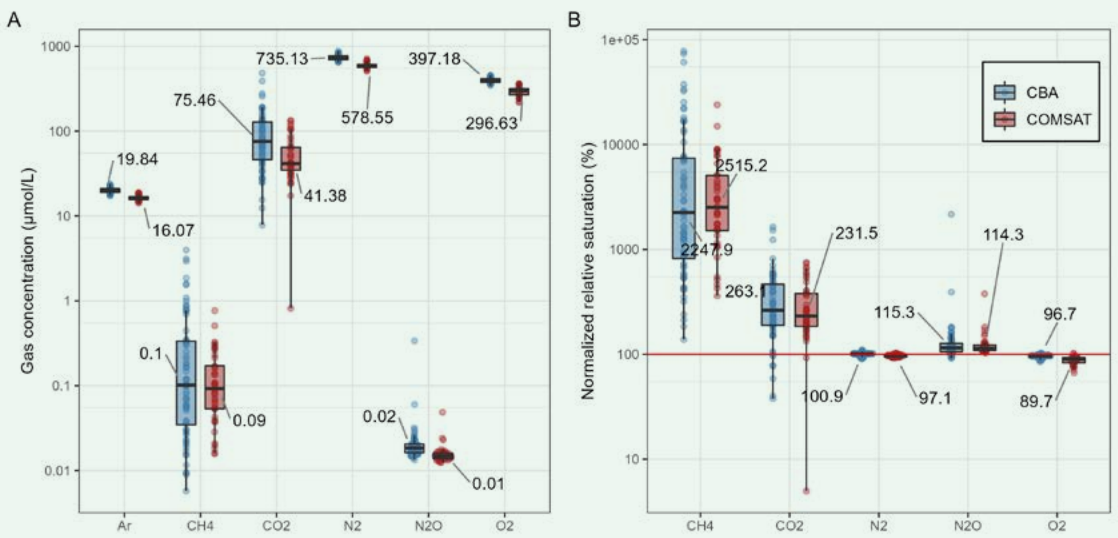

Figure 2: Surface water gas concentrations (A) and gas saturations (B) for CBA (blue) and COMSAT (red) datasets. Vertical axis are on a 10-base logarithmic scale. Data labels show median values for gas concentrations and saturations.

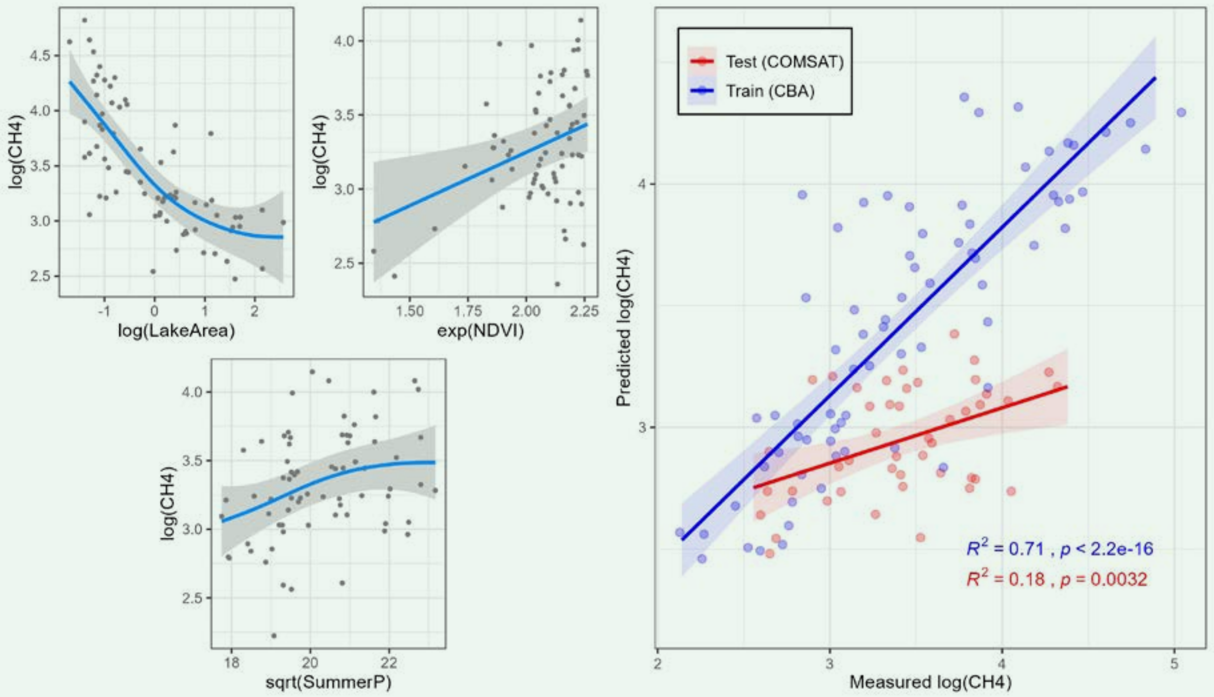

Figure 3: Simulations (blue lines) of normalized relative CH4 saturations in the CBA dataset by generalized additive model (GAM) 1. On the right side, model training with CBA dataset (red) and test with COMSAT dataset (blue) for each model. Shaded gray areas indicate 95% confidence intervals.

Figure 4: Sample processing in the field, including filtering water for further analyses and dissolved gas equilibration in situ.
Credits: Shaista Hassan

Such survey, conducted in autumn 2019 (known as "100 Lakes survey") helped to predict biotic saturation of CH_4, CO_2 and N_2O by using a set of chemical, hydrological, climate, and land use parameters. For this purpose, concentrations of GHGs and nutrients (organic C, -P, and -N) were determined in surface water samples from 73 lakes in south-eastern Norway covering a wide range in DOM and nutrient concentrations, as well as catchment properties and land use. The spatial variation in saturation of each GHG was related to explanatory variables.

Catchment characteristics (hydrological and climate parameters) such as lake size and summer precipitation, as well as NDVI were key determinants when fitting GAM models for CH4 and CO_2 saturation (explaining 71% and 54%, respectively), while summer precipitation and land use data were the best predictors for the N_2O saturation, explaining almost 50% of deviance. The main results suggested that lake size, precipitation, and terrestrial primary production in the watershed control the saturation of GHG in boreal lakes. These predictions based on the 73-lake dataset were validated against an independent dataset from 46 lakes in the same region performed in 2011 (COMSAT survey). Together, this provides an improved understanding of drivers and spatial variation in GHG saturation in boreal lakes across wide gradients of lake and catchment properties.

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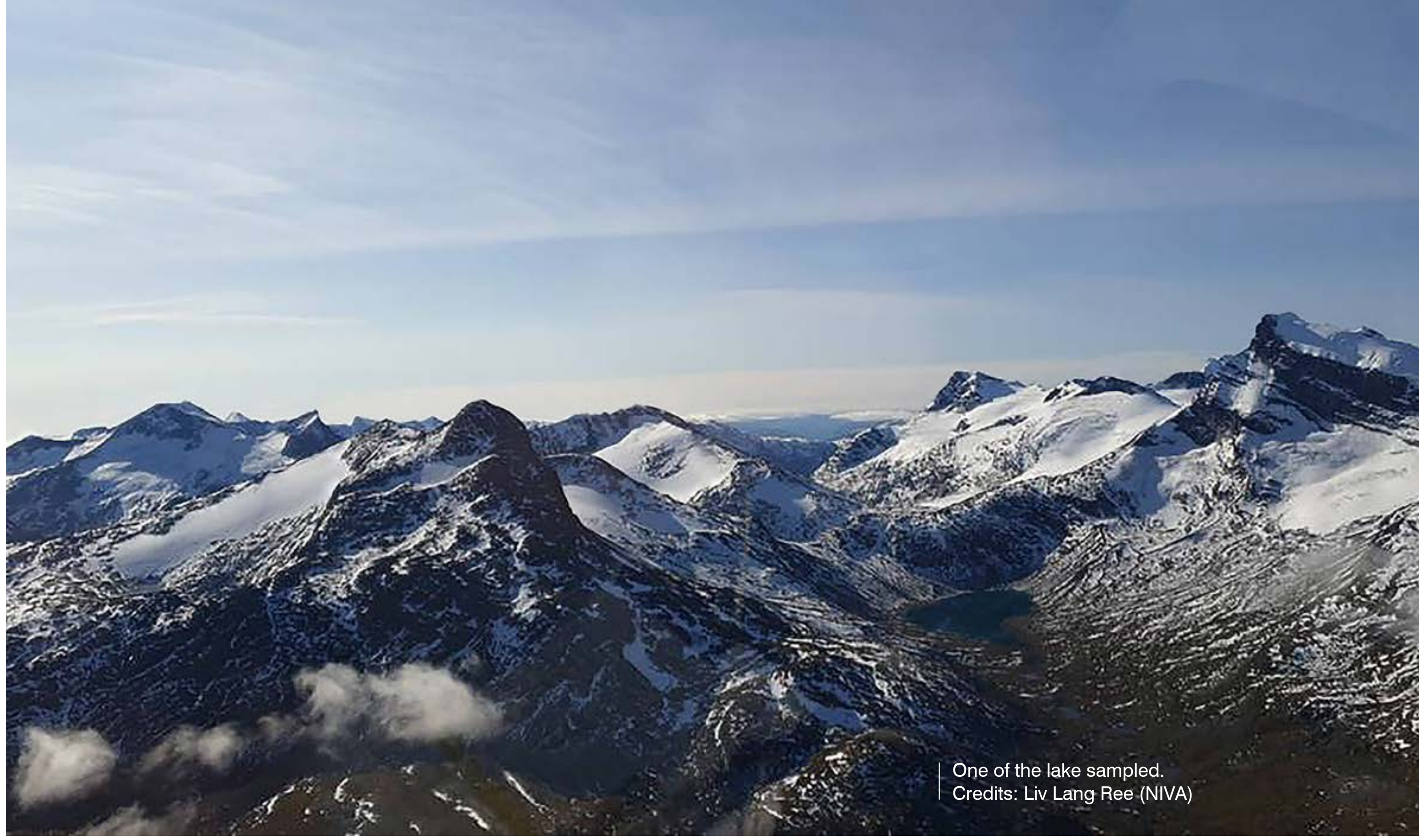
A tale of thousand lakes: expected and unexpected change



One of the lake sampled.
Credits: Liv Lang Ree (NIVA)

Heleen de Wit
Senior research scientist,
CBA and NIVA

&

François Clayer
Research scientist,
NIVA

A short historical background: acid deposition

A growing awareness of acid deposition's detrimental effects on fish populations inspired wide-scale collection of lake water data in the 1970s. This was an era of research where relations between acid rain, soil and soil water chemistry, water quality in rivers and lakes, and causes for fish mortality were discovered through experimental field manipulations, monitoring and modelling. New scientific knowledge was generated, resulting in science-based policy to reduce effects of acid rain. International collaboration, much akin to current collaboration on climate, resulted in the Convention for Longe-Range Transported Air Pollution and its associated Gothenburg Protocol (to Abate Acidification, Eutrophication and Ground-level Ozone; adopted in 1999, ratified in 2019). This is a success story for environmental research and protection: emissions of sulfur and nitrogen were reduced, deposition followed and damaging conditions for nature improved. So is this story over?

Trends in lakes chemistry

Let's have a look at the repeated Thousand Lake survey (1995 and 2019), set up to give regionally representative information on lake water quality status in Norway. Only natural, unlimed lakes were included. In a new paper published in Global Biogeochemical Cyles (de Wit et al. 2023), a comparison of the 1995 and the 2019 ThousandLake survey is presented. Comparison of two single years is tricky: it is always possible that observed change comes from interannual variation rather than as response to long-term change. Therefore, we tested if the direction of change between 1995 and 2019 was consistent with trends found in a much smaller lake survey, but with annual data (and a smaller set of chemical variables), e.g. the TrendLake survey – focused on 78 lakes from acid-sensitive regions exposed to significant levels of air pollution. Both surveys show consistent directional change, and we conclude that change found in the ThousandLake survey in pH, sulfate, base cations, alkalinity, aluminium, dissolved organic matter quantity and quality, nitrate and silica demonstrate long-term trends.

Some expectations confirmed, and some surprises

What did we see? An enormous reduction in sulfate, most conspicuous in south Norway (-65%) but also clear in North Norway (-17%), furthest away from the main sources of air pollution. This suggests less acid deposition, confirmed by air monitoring data, leading to water chemical recovery. Indeed, pH and alkalinity (mostly bicarbonates) increased while toxic aluminium (labile aluminium) decreased – indicating that conditions for aquatic life have much improved.

We expected that the strong decrease in acid anions (the equivalent sum of sulfate, chloride and nitrate) would be associated with a decline in counter-balancing base cations (calcium and magnesium) (following the principle of electroneutrality). To our surprise, we found both decreases and increases in calcium. Further prying into the data showed that these calcium increases were mostly in catchments with lower acid-sensitivity, that is, with higher base cation stores in soils for buffering atmospheric inputs of acidity. The decreases in calcium were limited to the most acidified catchments, in agreement with change shown elsewhere (Weyhenmeyer et al. 2019). A statistical analysis indicated that upward changes in calcium were closely associated with changes in alkalinity, suggesting that the carbonate system is more closely linked to calcium than so far assumed.

Atmosphere, soils and waters: it's all connected

Carbonates and calcium? Let's take one step back to look at factors that potentially affect change in calcium in soils and surface waters. First out is deposition of calcium, such as Saharan dust - which is usually very low in Norway, and cannot explain local variation that we observe. Second, there is a sink for calcium in vegetation, since vegetation requires base cations to grow. If anything, the need for base cations by vegetation should have increased since forest biomass in Norway has doubled since the 1970s, implying that the vegetation growth would lead to a reduced calcium in lakes. Third, soil stores of exchangeable calcium determine levels of calcium in lakes. These soil stores are quite low in Norway because of its acidic gneissic bedrock and removal of soils during glaciation. This is different in for instance Mediterranean countries with calcareous bedrock or in regions with new inputs of minerals, such as in catchments with retreating glaciers or thawing permafrost. These conditions are largely absent in the ThousandLake catchments. Worse, the calcium stores in soils have been depleted in large parts of Norway because of decades of acid deposition, soil acidification, mobilization, and increased export from soils to surface waters. Is it possible that these stores have been replenished more quickly than anticipated?

Øyvind Garmo (NIVA) is taking a water sample in one of the lake from helicopter. Credits: Frida Eklund (Helitrans)®

Liv Lang Ree (NIVA) is distributing the water into bottles. Credits: Frida Eklund (Helitrans)®

Pictures from the laboratory and water sample analyses. Credits: NIVA.

That would be by the least well-known of the processes that control calcium, i.e. mineral weathering. However, mineral weathering rates of the acidic bedrock of Norway have been considered to be so low that a few decades are not enough to replenish soils with calcium (and other base cations). Weathering rates under field conditions are difficult to measure and here data availability is low. Since there is so little data here, we have to turn to process understanding.

Weathering

Process-based models used to simulate effects of acid deposition on surface waters, such as the MAGIC model (Cosby et al. 1985), usually assume that weathering rates are constant. MAGIC has been successful in predicting surface water recovery in acid-sensitive regions in Europe and includes all key processes and element cycles that are important for acidification. MAGIC should be considered as that state of the art model that encompasses current understanding of acidification and chemical recovery.

A recent MAGIC-model test on the ThousandLakes from 1995 and 2019 (Kaste et al. 2022) showed that MAGIC underestimated chemical recovery somewhat, which was in particular related to underestimation of calcium. The model description of the 2019 lake chemical status was improved if soil base saturation and weathering rates were increased (by adapting model parameters), but this reduced model performance for the 1995 data. This suggests that the current understanding of surface water acidification, as embodied in MAGIC, is incomplete.

Weathering rates could be higher than state-of-the art models assume. Mineral weathering rates are known to increase with decreasing pH, and with increasing temperature and biological activity in the rhizosphere - where roots meet the soil. Soil acidification has been reduced, similar to surface water acidification, and thus cannot logically explain and increase in weathering rates. Soil warming is far slower than atmospheric warming, and no long-term trends in soil temperature are reported, to our knowledge. A large-scale change so far hardly mentioned is the increase in terrestrial productivity from lengthening of the growing season, warming, land use and possibly CO_2-fertilization. Whatever the driver, terrestrial productivity in Norway has increased as demonstrated by the increase in forest biomass, mentioned above. Weathering rates in forests are documented to be larger than in unvegetated areas, because of release of organic acids in the rhizosphere and through the ‘collaboration’ between funghi and roots, i.e. mycorrhiza. Funghi can actively mine the soil for nutrients – leading to increased weathering- but need carbohydrates as energy source, which they obtain from photosynthesizing vegetation.

A recent acceleration of the silicate-carbon cycle?

On a geological timescale, we know that silicate weathering has been important in reducing levels of atmospheric CO_2. Recent estimates of role in the global carbon cycle indicate that it is a net carbon sink of 1.1 Gt CO_2 year^{-1} (Ciais et al., 2013), where granite rocks, affected by acidiity from dissolved CO_2 result in mobilization of base cations, in particular Ca, which are leached from soils to surface waters and into the sea where it precipitates as $CaCO_3$. A simple representation of bedrock weathering can be written as follows, considering the weathering of wollastonite (CaSiO3) for stoichiometric simplicity:

$$CaSiO_{3(s)} + 2\,CO_{2(g)} + 3\,H_2O \rightarrow H_4SiO_{4(aq)} + 2HCO_3^-{}_{(aq)} + Ca^{2+}{}_{(aq)}$$

Thus, we speculate that the unexpected increase in Ca is related to a recent acceleration of the carbonate-silicate cycle. The mechanism would be that higher vegetation productivity is associated with increased production of root exudates and root respiration, leading to higher CO_2 pressure in the soil, contributing to higher concentrations of carbonic acid. This is substantiated by the strong increase in silicates (+40%) that we see in the ThousandLake data, which is especially clear in East and Middle Norway, where forest is most abundant.

It must be said that the increase in silicates may be explained in several ways: for instance from changes in hydrological flow paths, or lower uptake by diatoms in lakes. Additional evidence is needed to unravel these complex relationships. Better knowledge on variation in weathering rates across Norway would help, as would improved understanding on in-lake controls on SiO_2 through uptake in diatoms.

Conclusion

The ThousandLake survey has supplied important documentation of chemical lake recovery upon reduced acid deposition. The increase in lake calcium in catchments of lower acid-sensitivity may be linked to higher terrestrial productivity, suggesting a link between carbon cycling and geochemistry that is worthy of more attention.

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Weyhenmeyer GA, Hartmann J, Hessen DO, Kopacek J, Hejzlar J, Jacquet S, Hamilton SK, Verburg P, Leach TH, Schmid M, Flaim G, Noges T, Noges P, Wentzky VC, Rogora M, Rusak JA, Kosten S, Paterson AM, Teubner K, Higgins SN, Lawrence G, Kangur K, Kokorite I, Cerasino L, Funk C, Harvey R, Moatar F, de Wit HA, Zechmeister T (2019) Widespread diminishing anthropogenic effects on calcium in freshwaters. Scientific Reports 9.

Too much snow or too little snow: Why Warmer Winters Have a Worrisome Impact on The Arctic

Frans-Jan Parmentier
Researcher, Department of Geosciences

The Arctic is warming rapidly, more than three times as fast as the rest of the world. This warming is most intense in winter when extreme weather events, such as rain-on-snow and frost droughts, have led to wide-spread damage to vegetation. The ongoing warming of the cold season also raises soil temperatures and affects snow cover, which increases the thaw of permafrost and the loss of soil carbon. Despite this profound transformation of the cold season, land surface models have lacked the ability to accurately model wintertime impacts, and greenhouse gas emissions during the cold season, since they tended to prematurely switch off at the onset of winter.

The WINTERPROOF project aimed to fix this oversight by focusing on two themes: the vulnerability of vegetation to frost, and the impact of snow cover change on permafrost carbon loss. The first theme was explored by PhD student Marius Lambert at the CBA, and the second by PhD student Alexandra Pongracz at project partner Lund University in Sweden. Both of them successfully defended their PhD thesis in the winter of 2022/23. Marius worked with CLM-FATES, and Alexandra worked with LPJ-GUESS, which are two state-of-the-art dynamic vegetation models. The project further collaborated with Jarle Bjerke at NINA in Tromsø and Rosie Fisher at CICERO in Oslo.

Marius' work focused on introducing cold hardiness into CLM-FATES. Cold hardiness is the tolerance of vegetation to freezing, which follows from a number of physiological changes at the molecular level that arctic and boreal plants go through during autumn. Without a cold hardening scheme, the modeled vegetation would not survive the winter since it would dry out and die. Marius did not only fix this obvious issue, but also introduced the ability of the model to simulate realistic frost damage during extreme weather events. This occurs when temperature changes happen too fast for vegetation to adjust to, leaving them vulnerable to cold temperatures. For example, if a warm spell is followed by a sudden drop in temperature.

This is precisely what happened along the coast of northern Norway in early 2014, and we tested the model to see whether it could recreate the plant damage observed at the time. Our simulations showed a divergent impact between deciduous and evergreen species, where the latter incurred strong damage while deciduous species stayed hardened and remained undamaged. This contrasting response among species agrees with observations, and it suggests that an increasing frequency of extreme winter events may become a more important driver of species composition in the future.

Alexandra focused on how snow cover will affect the permafrost carbon feedback in the future. To do so, she first introduced a new snow scheme in LPJ-GUESS that more realistically simulated the internal dynamics of the snowpack, which strongly improved the thermal insulation of the snow. This led to a much more realistic simulation of soil temperature and permafrost extent when compared to observations. This model improvement gives confidence to our model projections of future snow change, which showed a contrasting response: while the Arctic will see a strong reduction in snow cover duration with climate warming, this same warming will also lead to more atmospheric moisture, which increases snowfall in areas where temperatures remain below zero. This is especially pronounced in regions close to the Arctic Ocean, where the loss of sea ice leads to more open water that can act a moisture source.

Our results show a strong increase in snow thickness in the coldest regions of the Arctic by the end of the century, even under the highest warming scenario. These increases in snow cover better shield the soil from cold winter temperatures, which causes an amplified warming of the soil and a stronger loss of permafrost carbon. This loss may be stronger than the amount of carbon taken up by vegetation. In other words: the thick snow cover acts as a blanket that accelerates permafrost thaw, and this may lead to a net release of greenhouse gases to the atmosphere.

WINTERPROOF has shown that climatic changes in winter act as a strong control on arctic carbon feedbacks. Not only because of the demanding conditions for vegetation survival, but also by being a highly important control on permafrost carbon loss. These outcomes have a high societal relevance, to inform the public and policymakers about the consequences of climate change on northern vegetation, and the potential for climate feedbacks from the release of greenhouse gases from permafrost soils.

WINTERPROOF project members enjoying a well-deserved lunch break during a field visit to Svalbard in 2019. Credits: Frans-Jan Parmentier.

The microbiome in the plastisphere

Alexander Eiler
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Department of Biosciences

&

Kristian Have Furnes
Master student, Department
of Biosciences

Kathleen Theresia Helleland
Master student, Department
of Biosciences

Franck Lejzerowicz
Postdoctoral fellow, Department
of Biosciences

The Marmib project which started in 2022 is funded by the Norwegian research council and will run until 2026. Here we aim to investigate the impact of microplastics (MP) on the spread of antimicrobial-resistant bacteria in marine environments. The project design includes incubations of known microplastic polymers worldwide including Vietnam, Norway, Baltic sea (Germany/Estonia), Costa Rica, and South Africa to follow biofilm formation and antimicrobial resistance spread.

Microplastics and antimicrobial resistance genes (including antibiotic products) are classified as types of pollution of concern. These two are suspected to be acting together and worsening a major problem facing the world today, the antimicrobial resistance crisis. Evidence has been accumulating which indicates that microplastics not only provide a surface for biofilm formation (the plastisphere), but they also enhance horizontal gene transfer and provide a physical vessel for spreading resistance genes across the globe, even to the low human impacted Arctic Ocean.

Project objectives:

1. Characterize the predominant MP profiles in the marine environment associated with high and low human impact.
2. Identify human and animal relevant microbial pathogens associated with the different MP profiles. In particular, what is the abundance and composition of fish pathogens close to Norwegian fish farms.
3. Compare AMR (Antimicrobial resistance) -profiles across different sampling areas and levels of human impact and characterize the resistome of the plasmidome in mariculture and urban waters.
4. Gain insights into the role of the MP microbiome for marine elemental cycles and ecological functions across different sampling areas and levels of human impact
5. Provide recommendations to be undertaken by the general public and policy making authorities to prevent AMR spread.

We carried out the first incubation along the Oslo docks in February 2023 using a prototype of what would eventually become a robust sampling device (figure 1A). A month later we would return to the prototype to find a thick biofilm had grown on it (figure 1B).

Figure 1: Current version of incubation device attached at Tjuvholmen. Made up of a box frame with 5 fishing lines attached horizontally. The fishing lines have polyvinyl chloride (PVC) and polystyrene (PS) plastic pieces and control rocks attached to the frame. In this frame, there are 36 pieces of PVC and PS, where each piece has 2 pads resulting in 72 samples per plastic-type, and 12 control rocks. Credits: Kristian Have Furnes and Franck Lejzerowicz.

Figure 2: The prototype incubation device consisted of a long fishing line with polystyrene pieces. It was attached near the Munch museum. The figure shows one of the leftover pieces that were not sampled, hence the gloveless handling. As seen it is covered in a brownish color which is the biofilm. Credits: Anoushka Nordby, Oslo Fjord CleanUP.

Figure 3. Master students Kristian Have Furnes and Kathleen Helleland preparing the material (left) and the Fjord CleanUP team (right) with Kristian Have Furnes, Dr. Franck Lejzerowicz, Anoushka Nordby and Tomas Hansson. Credits: Anoushka Nordby, Oslo Fjord CleanUP.

Collaborators

Dr. Odd-Gunnar Wilmark
(NORCE - Tromsø)

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(NORCE - Tromsø)

Prof. Hans-Peter Grossart
(IGB-Berlin, Germany)

Prof. Keilor Rojas Jiménez
(Universidad de Costa Rica)

Prof. María de Jesús Arias Andrés
(Universidad Nacional, Costa Rica)

Dr. Veljo Kisand
(University of Tartu, Estonia)

Prof. Carlos Bezuidenhout
(North West University, South Africa)

Dr. Thuy Chung Kieu Le
(Ho Chi Minh City University of Technology, Vietnam)

Dr. Emilie Strady
(University of Aix Marseille & Toulon, CNRS/IRD, France)

Prof. Lorenzo Brusetti
(Free University of Bozen-Bolzano)

Federica Piergiacomo
(PhD candidate)

Scientific: Marmib

Non-Scientific: Fjord CleanUP

Fjord CleanUP

The "Hurdal platform"

View over the Hurdal Lake with surrounding, boreal forest from the platform on top of the tower at the ICOS project. Here net fluxes of CO_2 and CH_4 from the surrounding forests are monitored. The site was visited during the annual CBA meeting which in 2022 was held at the Hurdalsjøen Hotel This site is renowned for hosting governmental budget meetings and not the least by serving as the site for negotiations and formation of the current government in Norway through a more recognized "platform". The Government's political platform known as "The Hurdal Platform" states the importance of climate in this way; Addressing the climate crisis is the greatest challenge of our time. Climate and environmental considerations will be at the core of all government policy. Norway's ambitious climate targets apply to the entire Government and all sectors of society. These targets must be met. Put forward a proposal for international climate cooperation between the countries that have boreal forests. Even more important, the platform states that "Climate and environmental considerations will be at the core of all government policy" (In Norwegian: "Klima og natur skal være en ramme rundt all politikk"). The climate-nature interaction is actually to the core of CBAs activities.

Photo: Getty Images

Outreach

CBAs researchers love to engage in public outreach. They participate in public debates, create newspaper articles and write books, and look forward to doing this even more in the years to come.

Outreach 2022

Chronicles and popular science

24 Chronicles and interviews

19 Talks and presentations

2 podcasts and videos

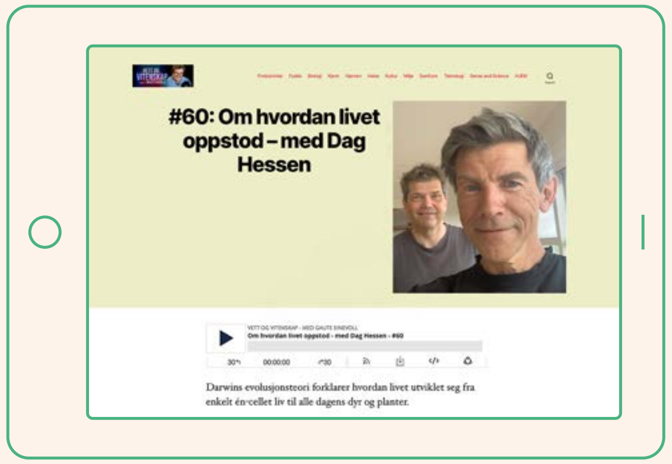
Selected talks and presentations

- Presentation at The Norwegian Parliment (Stortinget) of climate and IPCC
  D. O. Hessen, January 13
- Panelist and presenter at the UNESCO conference on Universities and the SDGs
  D. O. Hessen, January 13.
- Presentation at the SDG-conference at University of Bergen
  D. O. Hessen, January 26.
- Presentation at the Conference "Let us talk about tomorrow…, The Grieg Hall, Bergen
  D. O. Hessen, January 31.
- Climate presentation for the Aker company
  D. O. Hessen, March 30.
- The origin of life, House of Literature, Trondheim
  D. O. Hessen, April 6.
- Climate presentation and discussions at «Industriuka», Porsgrunn
  D. O. Hessen, April 21.
- Climate and nature, Finance Norway
  D. O. Hessen, April 27.
- Climate and nature, NITO, Oslo
  D. O. Hessen, May 12.
- Presentation of the UNESCO-report on SDG and higher education
  eds. D. Hessen and S. Schmelkes, Barcelona , May 18.
- On Nature loss and climate, Olavsuka, Trondheim
  D. O. Hessen, August 3.
- Three discussions and presentations at Arendalsuka
  D. O. Hessen, August 18.
- Lecture on permafrost carbon cycle, Miljødirektorat,
  S. Westermann, September 2.
- Hvorfor har urørt natur egenverdi? Om i morgen.
  D. O. Hessen, September 7.
- Lecture on green technology conference, SINTEF:
  D. O. Hessen, October 2.
- Lecture on climate and nature loss, House of Climate.
  D. O. Hessen, October 3.
- Lecture on climate and nature, the directorate for constructions.
  D. O. Hessen, October 9.
- Panel discussion on nature loss, Directorate of the Environment and the Norwegian Research Council.
  D. O. Hessen, November 23.
- Christmas lecture on permafrost carbon cycle, Klima- og miljødepartementet
  S. Westermann, December 2.

Chronicles and interviews

- Forestry, water quality and ecology
  Skarbøvik, E., Aroviita, J., Kaste, Ø., Lepistö, A., Rajakallio, M., de Wit, H. BIOWATER Policy Brief No. 1 2022.
- Fotosyntesen redder ikke klimaet
  Vollsnes, A.V., Stordal, F. & Bryn, A. Nationen, January 25.
- En nær uutholdelig tanke – tilbakekoblinger og vippepunkter i Antropocen.
  D. O. Hessen, Morgenbladet, January 27.
- Vil ha bærekraft inn i all utdanning
  D. O. Hessen, interview, Khrono, February 7.
- Hjelp fra vulkanen?
  F.J.W. Parmentier, Klassekampen, February 18.
- Problemet med intelligent design
  J. Giske, D. Hessen, G.P. Sætre, Vårt Land, Mars 1.
- Skogen utfordres i nytt klima
  Bryn, A., Vollsnes, A.V. & Stordal, F. Nationen, April 2.
- Byggestopp i naturen er et nødvendig klimatiltak
  C. Aal, D. Hessen, V. Vandvik, Nationen, April 20.
- Universities as catalysts of transition to sustainability
  D. O. Hessen, University World News, April 20.
- Vi må ta naturens reelle verdi inn i beregningene
  D. O. Hessen, V. Vandvik, Dagens Næringsliv, April 23.
- Biologiprofessor utfordrer LO til å ta diskusjonen om hvilket samfunn vi skal leve i framover
  D. O. Hessen, interview, Fri Fagbevegelse, April 25.
- Skal universitetene redde verden?
  D. O. Hessen, Morgenbladet May 4.
- Langt, langt borte
  F.J.W. Parmentier, Klassekampen, May 13.
- Bør vi snakke mer om hvor galt det kan gå?
  D. O. Hessen, B. Samset, interview, Dagsavisen, August 8.
- Ekstremoppvarmingen av Arktis gir økte CO_2-utslipp
  F.-J. Parmentier, D.O. Hessen, Y-R Wang, Dagens Næringsliv, August 23.
- Klimaendringer: For å gjøre det som kreves, trenger vi kanskje å bli litt skremt
  Forskning.no. Dag O. Hessen. September 21.
- Det burde være mulig å vise mer respekt for forskere
  D. O. Hessen, T. Storelvmo, A. Kääb, Khrono, October 4.
- På vippepunktet. Hva skjer hvis karbonet som er lagret dypt i permafrosten, slipper ut?
  Klassekampen. Frans-Jan Parmentier. October, 14.
- Kunnskap for en ny tid
  Samset, B.H., Hessen, D.O., Sverdrup-Thygeson, A., Einevoll, G., NRK Ytring, October 31.
- In vitro-fertilisering – nye metoder, nye muligheter, nye mennesker
  Hanevik, H.I., Hessen, D.O., Tidsskriftet, November 7.
- Klimaendring er ikke som ¬å skru opp varmen med en grad
  F.J.W. Parmentier, Klassekampen, November 21.
- Hvem har en politikk for framtiden?
  D. O. Hessen, Morgenbladet, November 27.
- Vil naturen rydde opp etter festen?
  Hessen, D.O., Samset, B.H., Kverndokk, S., NRK December 6.
- Må naturen vike for å redde klimaet?
  D. O. Hessen, Biolog 1/2022.

Media



Podcast #60:
Om hvordan livet oppstod

Einevoll, G., Hessen, D.O., 2022.
Vett og vitenskap.

https://vettogvitenskap.no/vov60/

Entrevista a Nicolás Valiente Parra

Investigador español en el proyecto
Artic Biodiver. V. Parra.
Spanish ambassy in Norway.

https://www.youtube.com/watch?v=qFuL2WNnPIs N

Reports

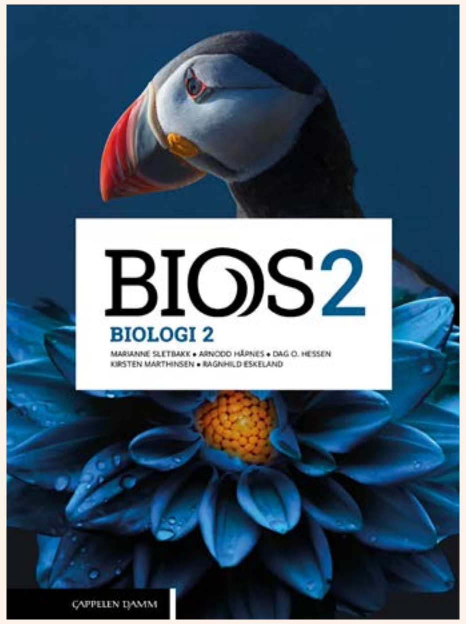
- **Case study on impacts of large-scale re-/afforestation on ecosystem services in Nordic regions. NEGEM project**
  Vogt, R.D., de Wit, H., Koponen, K., 2022a.
- **Impacts of large-scale forest related NETPs on climate and ecosystem services in Nordic region. Impacts of large-scale forest related NETPs on climate and ecosystem services in Nordic region**
  Vogt, R.D., de Wit, H., Koponen, K., 2022b.

Other

- **Matproduksjon, mattrygghet og miljø – innspill om kunnskapsbehov til gjennomføringen av det grønne skiftet – Uttalelse fra hovedkomiteen i Vitenskapskomiteen for mat og miljø (VKM). VKM Report 2022:30, 1–21**
  Alexander, J., Hemre, G.I., Hofshagen, M., Mathisen, G.H., Aasmo-Finne, M., Agdestein, A., Bodin, J.E., Bruzell, E.M., Elvevoll, E.O., Hessen, D.O., Husøy, T., Knutsen, H.K., Krogdahl, Å., Nilsen, A.M., Rafoss, T., Skjerdal, O.T., Steffensen, I.-L.K., Strand, T.A., Vandvik, V., Velle, G., Wasteson, Y., 2022.
- **Benefit and risk assessment of fish in the Norwegian diet – Scientific Opinion of the Steering Committee of the Norwegian Scientific Committee for Food and Environment. VKM Report 2022**
  Andersen, L.F., Berstad, P., Bukhvalova, B.A., Carlsen, M.H., Dahl, L.J., Goksøyr, A., Jakobsen, L.S., Knutsen, H.K., Kvestad, I., Lillegaard, I.T.L., Mangschou, B., Meyer, H.E., Parr, C.L., Rakkestad, K.E., Rasinger, J., Sengupta, S., Skeie, G., Starrfelt, J., Ulven, S.M., Agdestein, A., Bodin, J.E., Bruzell, E.M., Elvevoll, E.O., Hemre, G.I., Hessen, D.O., Husøy, T., Krogdahl, Å., Nilsen, A.M., Skjerdal, O.T., Steffensen, I.-L., Strand, T.A., Vandvik, V., Velle, G., Wasteson, Y., Alexander, J., 2022.

Books and award 2022

Book



Bios 2 Biologi 2
(LK20)

Cappelen Damm Akademisk. Lærebok i biologi 2 realfaglig utdanningsprogram

Marianne, S., Arnodd, H., Hessen, D.O., Kristin, M., Eskeland, R., 2022. Bios 2 Biologi 2 (LK20),

> Education is an important component of the CBA activities, and CBA has been involved in this by Dag Hessen as coauthor of a series of textbooks at the high-school levels, like this latest from 2022.

Book chapter

- Current knowledge and uncertainties associated with the Arctic greenhouse gas budget, in: Balancing Greenhouse Gas Budgets.
  Euskirchen, E.S., Bruhwiler, L.M., Commane, R., Parmentier, F.-J.W., Schädel, C., Schuur, E.A.G., Watts, J., 2022. Elsevier, pp. 159–201.
  https://doi.org/10.1016/B978-0-12-814952-2.00007-1

Research dean Bjørn Jamtveit presented this year's Titan award to Dag O. Hessen. Photo: Elina Melteig.

2022 Titan award

The 2022 Titan award was given to biology professor Dag O. Hessen, who has prioritized communication throughout his career.

The Titan prize is awarded annually to a researcher who has made an unusual and outstanding effort to tell about the research at the MN faculty.

Dag Olav Hessen is not just a professor. He is also one of the few researchers who is invited to Debatten or Nytt på nytt, and other TV and radio programmes. He is someone that many people look up to and listen to, and much of this is probably due to a long-term commitment to communicating the subject of biology. At the same time, he is also an active researcher and head of the Center of Biogeochemistry in the Anthropocene (CBA). – This year's award winner has distinguished himself as a steady communicator over a number of years, and it is probably correct to call him the MN faculty's only "celebrity". He has achieved this status through being a particularly active and clear voice and conveys about evolution, climate, ecology and the importance of biology for the understanding of man, says Bjørn Jamtveit, who is research dean at the Faculty of Mathematics and Natural Sciences at the University of Oslo.

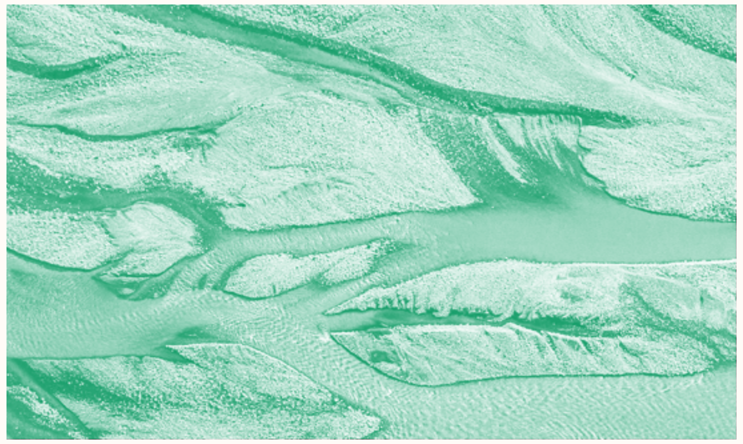
– Hessen has particularly promoted the message of how important it is to take care of nature there in the face of the climate crisis. Here, we experience you as a very clear voice. The climate and nature crisis is now at the top of the political agenda, which has led to extra pressure on knowledge providers in this area recently, says Jamtveit.

With this award, we would like to thank you for your outstanding communication efforts. You are without a doubt one of MN's absolute best communicators, says Jamtveit.

Photo: Getty Images

CBA Events

CBA events



Annual Lecture

October

- Professor **Lars Bakken** from Norwegian University of Life Sciences.
- Title – *The nitrogen cycle – from gene to system*

Workshop

May 30–31.

Norwegian coastal ecosystem dynamics (ekoNOrd)

Hosted by CBA researcher **Yeliz Yilmaz,** to foster collaboration between Oslo and Kiel universities on researching Norwegian coastal ecosystem dynamics under a changing climate.

Academic Exchange between Kiel and Oslo universities to collaborate on researching NORwegian coastal ecosystem Dynamics (ekoNOrd).

October 11.

Nordic Climate Tipping Points: How to Prepare for a Non-linear Future

– Science-Policy Workshop. Organized by Manjan Milkoreit, Christina Nadeau and Stephanie Schmölzer. The workshop brought together natural and social scientist as well as policy makers to explore specific climate risks facing the Nordic region.

Guest lectures

April 29.

- Associate Professor **Anna Maria Romani Cornet,** University of Girona
- Title – *Biofilm responses to stress factors, drought and others…and effects on biogeochemical processes*

- Researcher **Hannes Markus Peter,** EPFL (École polytechnique fédérale de Lausanne)
- Title – *Microbial Ecology of alpine streams – from microdiverse bacterial to viral communities*

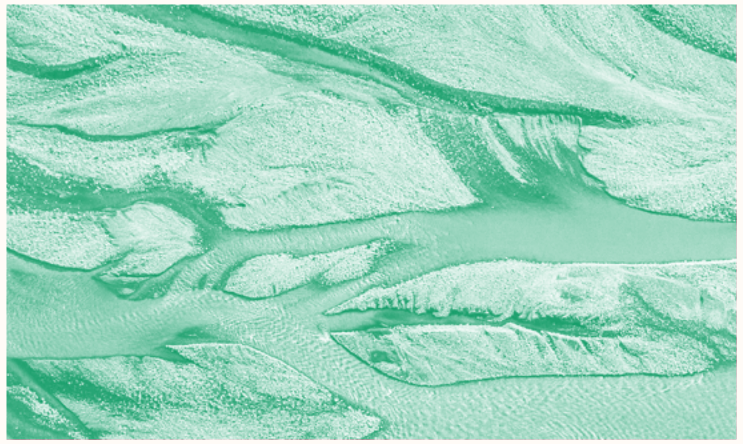
November 3.

- Professor **Lars Tranvik,** University of Uppsala
- Title – *Contributions of lakes to the carbon cycle*

- Professor **Emma Kritzberg,** University of Lund
- Title – *Drivers of long-term browning*

- Professor **James B. Cotner,** University of Minnesota
- Title – *What makes carbon recalcitrant in lakes and oceans? The roles of microbes, light and hydrology*

Internal CBA events



PhD defense

June 16.

- **Maja Nipen** – Spatial and temporal trends of anthropogenic pollutants in a tropical, urban environment in East Africa.

June 30.

- **Wen Tan** – The atmospheric fate of selected amines emitted from carbon capture facilities.

November 4.

- **Lina Allesson** – CO_2:O_2 balance in boreal freshwaters in a changing climate

December 20.

- **Marius Lambert** – Modelling the critical role of cold acclimation for vegetation survival during extreme winter weather.

Tuesday talks 2022

Tue

CBA internal seminar 2022

March 8

- **Camille Crapart** – Modelling of TOC concentration in Fennoscandia

March 22

- **Aleksandr Berezovski** – Green-blue link made browner: how terrestrial climate change affects marine ecology

April 5

- **Elin Aas** – A modeling approach to belowground biogeochemistry

April 19

- **Devaraju Narayanappa** – Green-blue link made browner: Modeling the lateral flow of dissolved organic carbon

Mai 3

- **Alexander Haaland** – Trace Gas Emission from Cattle Husbandry

2022

CBA annual meeting

The CBA annual meeting was held in Hurdal September 26–27 2022

Monday 26th September

- **Dag Olav Hessen** – CBA-status, highlights, and future: Into the BioGov
- **Holger Lange** – The ICOS project and terrestrial carbon fluxes
- **Alexander Eiler** – BioGov WP1. Biological decomposition of SOM and NOM
- **Frans-Jan Parmentier** – BioGov WP2. Plant hydraulics and frost damage in FATES
- **Heleen de Wit** – BioGov WP3. Repeated sampling of thousand Norwegian lakes reveals widespread changes in silica, aluminium and DOC. Responses to cleaner air or climate change?
- **Anders Bryn** – Tree- and forest line dynamics in Norway: causes and consequences
- **Sabrina Schultze** – Effect of terrestrial and aquatic dissolved organic matter on uptake of teflubenzuron in mussels and ascidians
- **Sebastian Westermann** – BioGov WP4: Overview over BioGov study sites in Finnmark
- **Terje Berntsen** – BioGov WP5. Climate modelling
- **Peter Dörsch:** Studying metabolic responses by gas chromatography
- **Francois Clayer** – Lessons learned from two method tests on dissolved gases and dark incubations
- **Armin Wisthaler** – Measurement Capabilities of the Atmospheric Chemistry Group
- **William Hagopian** – Instrumental Capabilities of CLIPT Lab
- **Christina Nadeau** – Tipping Points: From Climate Crisis to Positive Transformation – A Summary

Tuesday 27th September

- **Lena M. Tallaksen** – LATICE and EMERALD from a hydrological perspective
- **Heleen de Wit and Jacqueline Knutson** – Investigating hydrology and carbon cycling connections in peatland permafrost, northern Norway
- **Astrid Vatne and Ane Vollsnes** – Drought through increased air VPD or lowered soil water content have different effects on Betula nana leaves
- **Michael A. Bekken** – Charactecizing the water chemistry, soil properties, and carbon balance of the Hisåsen site
- New faces – **Eira Carlsen, Elisabeth Wörner, Mats Rouven Ippach**
- **You-Ren Wang** – Global trends of diurnal temperature range by land cover types with MODIS remote sensing
- **Kristoffer Aalstad** – Learning from Earth observations using data assimilation
- **Esteban Alonso-González** – Snow and fire: Facilitating the study of major surface modifiers by earth observations
- **Yeliz Yilmaz** – Evaluating modeled snow cover dynamics over Fennoscandia using Earth observations and reanalyses
- **Camille Crapart** – Pathways for future TOC concentration in boreal lakes
- **Elin Ristorp** – Aas Nitrogen limitations in a soil decomposition model
- **Jing Wei** – Trajectories in greenhouse gas saturation and microbial genomics upon glacial retreat
- **Cathrine Brecke Gundersen** – The quality of DOM using fluorescence excitation emission matrix (EEM) PARAFAC.

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Education

Education

Courses at CBA

CBA's researchers teach several courses on topics related to biogeochemistry.

KJM1700

Environmental and climate challenges

The course provides a basic scientific introduction to the environmental challenges and several of the UN's sustainability goals, and how environmental authorities use scientific insights. A group project assignment provides an in-depth look at a chosen environmental theme and training in scientific publishing. The course has an interdisciplinary approach that makes it suitable for students from other disciplines who need basic knowledge of the environment and climate in the academic community.

BIOS3070/KJM3070

Biogeochemistry

The global environment is tightly linked to the global cycles of carbon and other key elements like nitrogen, phosphorus and iron. These elements are also closely related to the hydrological cycle as well as biological production, diversity and ecosystem services, and chemical properties of the environment. The course will focus on couplings between biological, geological and chemical processes, on the interactions between climate and the environment, and human impacts on these processes.

The lectures are common for the courses KJM3070 and KJM4070 while most of the colloquia, workshops and labs are being held separately.

TFF3219

Cross-disciplinary ecology in the Anthropocene

Anthropocene, the age of humans, is suggested as the name for the geological epoch that we are currently in. Humans are seen as the most important force in the large changes that can be observed in climatic patterns, atmosphere, biodiversity, cryosphere, seas and lakes. IPCC has stated that the climate change is caused by anthropogenic activity, indicating a new link between humans and nature.

This implies a cross-disciplinary challenge for any scientific discipline, from humanities and social sciences to biology, geology and other natural sciences. With the cross-disciplinary research project ECODISTURB as our starting point, this course provides an opportunity to understand and discuss the cross-disciplinary challenges arising in the Anthropocene.

GEO4161

Contaminants in the geoenvironment

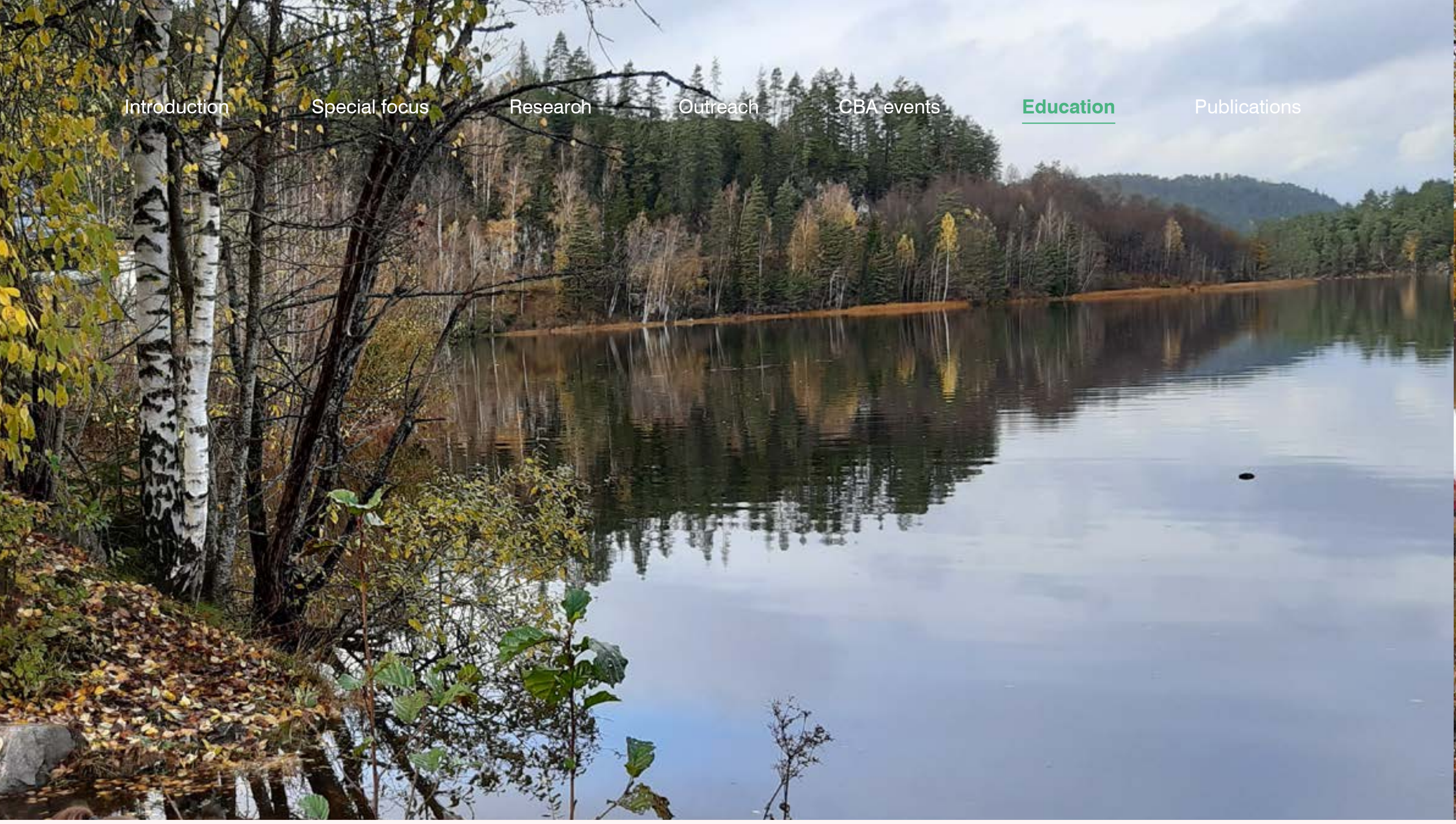
Contaminants in soils and ground water pose a threat to our society and the limited land and water resources. The course will cover:

- Types of contaminants, both organic and inorganic
- Physical/chemical distribution among phases/media
- Biogeochemical processes in soils and groundwater
- Transport of contaminants
- Risk assessment
- Natural attenuation

BIOS4500

General Toxicology

The course will cover basic toxicology and ecotoxicology, including how toxic substances are taken up in the organisms, distributed, biotransformed and excreted, how toxic substances react with biomolecules and downstream consequenses for the organism, as well as knowledge about toxic substances, e.g. metals, organic contaminants and pesticides. The course aims to provide a holistic view of the topic by bridging human toxicology and ecotoxicology.



GEO4904

Atmospheric Chemistry

The course deals with the basic processes that govern the composition of chemically active species in the atmosphere (gases and aerosols). This is crucial in understanding trends in short-lived greenhouse gases, aerosols, ozone depletion in the stratosphere, acidification and regional air pollution. The course gives an introduction to modelling of atmospheric chemistry in e.g. Earth System Models.

KJM5700

Environmental Chemistry

The course provides an integrated description of the chemical processes and equilibrium systems that determine mobility, transport, turnover and effects of chemical contaminants in air, soil and water. It also provides an introduction to natural chemical processes in the environment. The lectures are given by external and internal researchers with examples from our own current research.

GEO5900

Chemical processes in soil and ground water

The main geochemical reactions controling the chemical composition of soil and ground water are treated in detail, and how these can be quantified and used in interpreting different processes effecting the water quality. Equilibria and kinetics in water-mineral-gas systems are covered, with special emphasis on CO_2 - carbonate reactions, mineral weathering, redox-reactions, ion exchange, sorption, and pollution of organic chemicals. An understanding of these procecces and a corresponding quantification is required to predict the effect of contaminant spill and human influence. Lectures and home works are accompanied by training in computer modeling of geochemical reactions and transport of solutes in groundwater.

BIOS5411

Toxicants in ecosystems and humans: effects

The course gives insight into how toxicants affects humans and the environment, with a particular focus on individual effects. Toxicants affect many of the same processes in different organisms and the course will discuss similarities and differences between different species, using mammalian toxicology as a starting point. The course includes aspects of both ecotoxicology and human toxicology.

BIOS5412

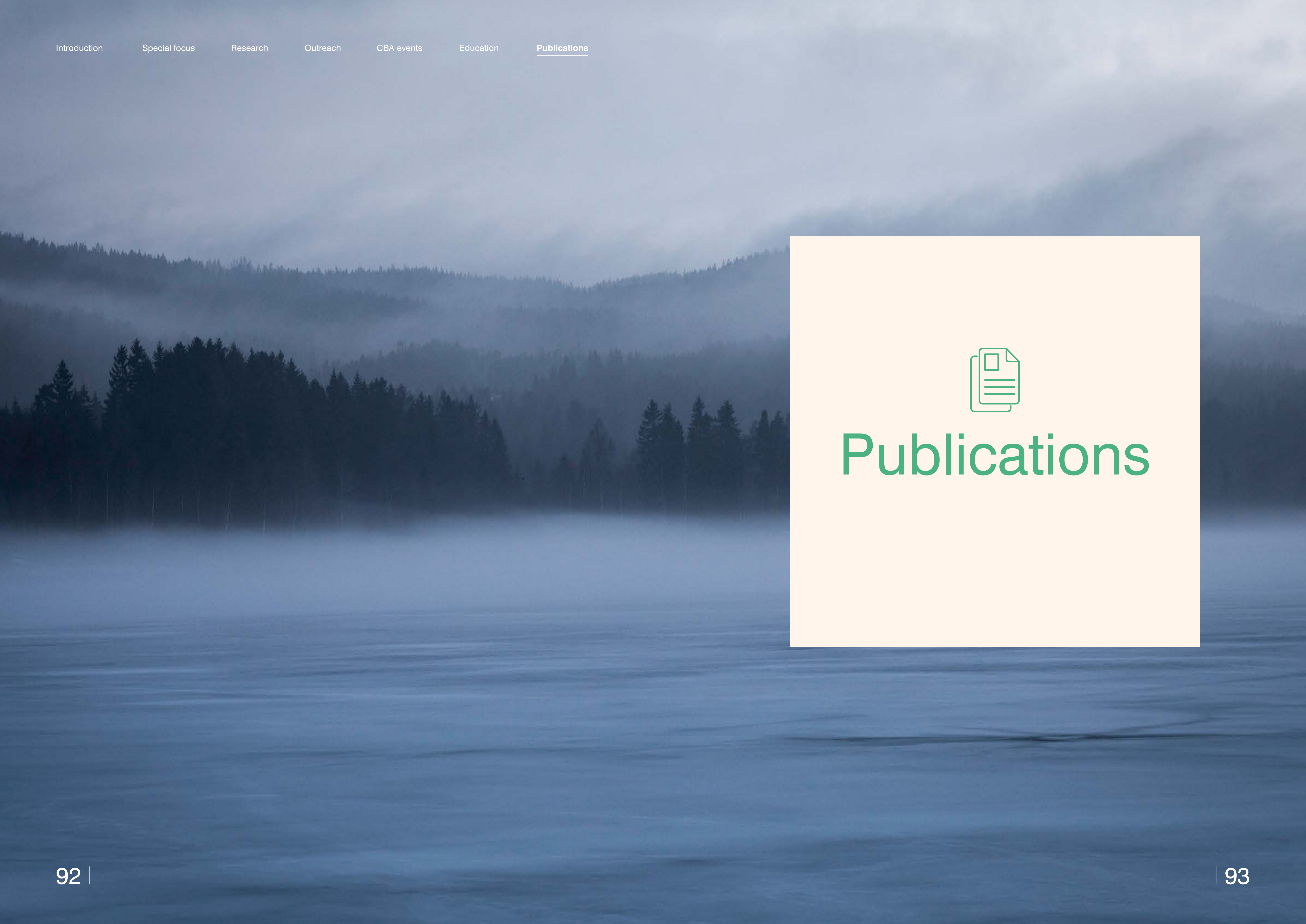
Toxicants in Ecosystems and Humans: Exposure and Accumulation

The course gives insight into how toxicants are distributed in the environment and accumulated by humans and other organisms. The course focuses on mechanisms and processes that are important to understand distribution and accumulation of toxicants and how these processes are affected by other stressors, physiological and ecological adaptations, life history traits and the phylogenetic history of the organism. The course encompasses both different ecosystems, including organisms, and humans.

GEO9915

Ecological Climatology

The course provides an overview of the relationships between climate and ecology, with focus on climate related feedbacks within boreal, alpine and arctic terrestrial ecosystems. Through the program, students will understand the connections and interactions between land and atmosphere, with an emphasis on terrestrial vegetation ecology and dynamic vegetation modeling. The main focus will be on processes at northern latitudes.



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CBA's economy in short

CBA is a centre directly under the Faculty of Mathematics and Natural Sciences, and financially supported by the Faculty via the three involved institutes; Biosciences, Chemistry and Geosciences, initially for a period of five years from 2018. This amounts to 500 000 NOK per institute and covers the salary costs of a centre coordinator, a PhD student and a postdoctoral researcher directly employed by CBA, in addition to some running costs. Other CBA researchers are employed at the departments of biosciences, geosciences and chemistry. On top of these basic grants comes project grants from the Research Council of Norway, EU and other sources, plus 2-3 PhD-positions ("KD-stipendiates" from the Faculty.

The economic model of CBA is based on a shared division of overhead from external projects, where 60% of overhead is assigned to the respective institutes and 40% is allocated to CBA. Thus over time the direct faculty support will be replaced by such overhead costs from externally funded projects. CBA runs, or is part of, several such externally funded research projects, some of which are presented through this report.

Starting from September 2022, CBA has received funding from the Norwegian Research Council for the project «Biogeochemical processes Governing boreal C cycling» (BioGov), with a total budget of 25 mill NOK. This project will run until 2027, and include a major fraction of the permanent staff at CBA in all three institutes. Also several PhD-students and postdoctoral researchers will be hired under this project, and many master students are affiliated with budget allocations from the respective departments. Several other project proposals are submitted and is under consideration, including personal ERC-grants. CBA was also central in an application for a Centre of Excellence, named ACT – Arctic Climate transitions. ACT was among the 11 that was recommended for granting – until budget cuts for the Research Council reduced the numbers. Increased costs at the Faculty and the UiO-levels may over time indirectly affect CBA as well, which motivated for intensified grant applications.

Centre for Biogeochemistry in the Anthropocene

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