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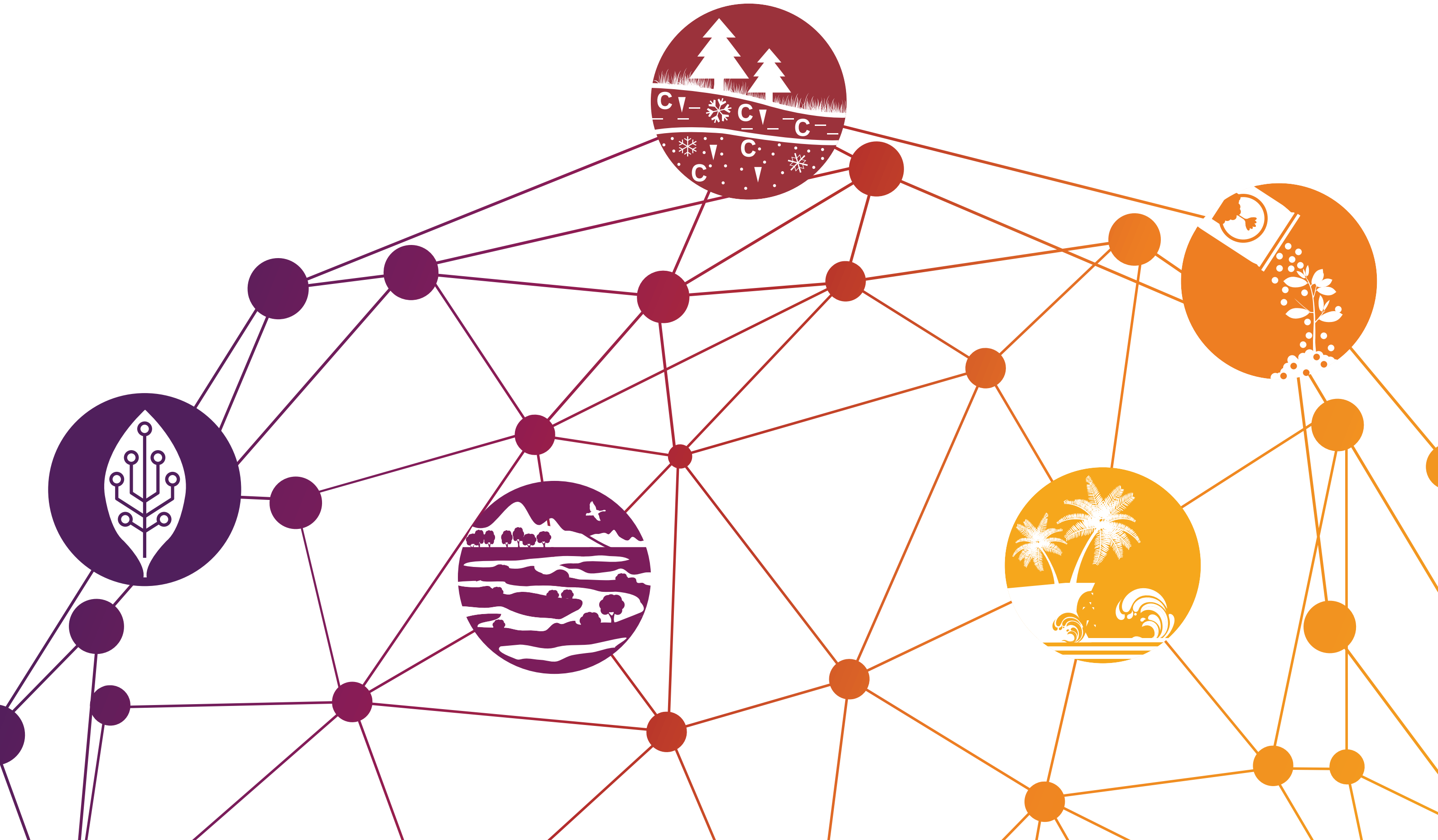
FRONTIERS 2018/19

Emerging Issues of Environmental Concern



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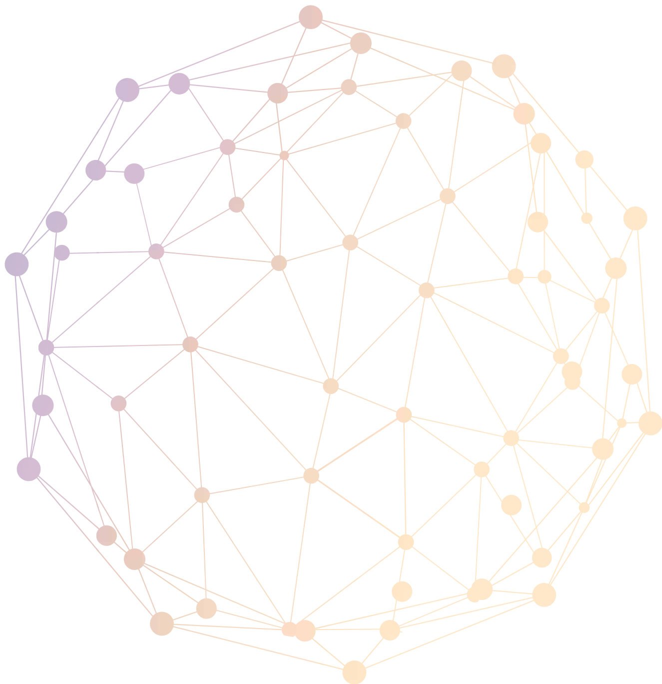
Emerging Issues of Environmental Concern



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Foreword

In the first decade of the 20th century, two German chemists – Fritz Haber and Carl Bosch – developed a way to produce synthetic nitrogen cheaply and on a large scale. Their invention spurred the mass production of nitrogen-based fertilizers, and thus transformed farming around the globe. It also marked the beginning of our long-term interference with the Earth's nitrogen balance. Every year, an estimated US$200 billion worth of reactive nitrogen is now lost into the environment, where it degrades our soils, pollutes our air and triggers the spread of "dead zones" and toxic algal blooms in our waterways.

It's no wonder that many scientists are arguing that "the Anthropocene" should become the official name of the current geological era. In just a few decades, humankind has caused global temperatures to rise 170 times faster than the natural rate. We have also deliberately modified more than 75 per cent of the planet's land surface, and permanently altered the flow of more than 93 per cent of the world's rivers. We are not only causing drastic changes to the biosphere, we are also now capable of rewriting – and even creating from scratch – the very building blocks of life.

Every year a network of scientists, experts and institutions across the world work with UN Environment to identify and analyze emerging issues that will have profound effects on our society, economy and environment. Some of these issues are linked to new technologies that have astonishing applications and uncertain risks, while others are perennial issues, such as the fragmentation of wild landscapes and the thawing of long-frozen soil. Another issue, nitrogen pollution, represents an unintended consequence of decades of human activity in the biosphere. While the final issue analyzed here, maladaptation to climate change, highlights our failure to adequately and appropriately adjust to the shifting world around us.

There is some good news to report. As you can read in the pages that follow, a holistic approach to the global challenge of nitrogen management is beginning to emerge. In China, India and the European Union, we are seeing promising new efforts to reduce losses and improve the efficiency of nitrogen fertilizers. Ultimately, the recovery and recycling of nitrogen, as well as other valuable nutrients and materials, can help us to farm cleanly and sustainably, a hallmark of a truly circular economy.

The issues examined in Frontiers should serve as a reminder that, whenever we interfere with nature – whether at the global scale or the molecular level – we risk creating long-lasting impacts on our planetary home. But by acting with foresight and by working together, we can stay ahead of these issues and craft solutions that will serve us all, for generations to come.

Joyce Msuya
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Synthetic Biology: Re-engineering the environment

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Permafrost Peatlands: Losing ground in a warming world

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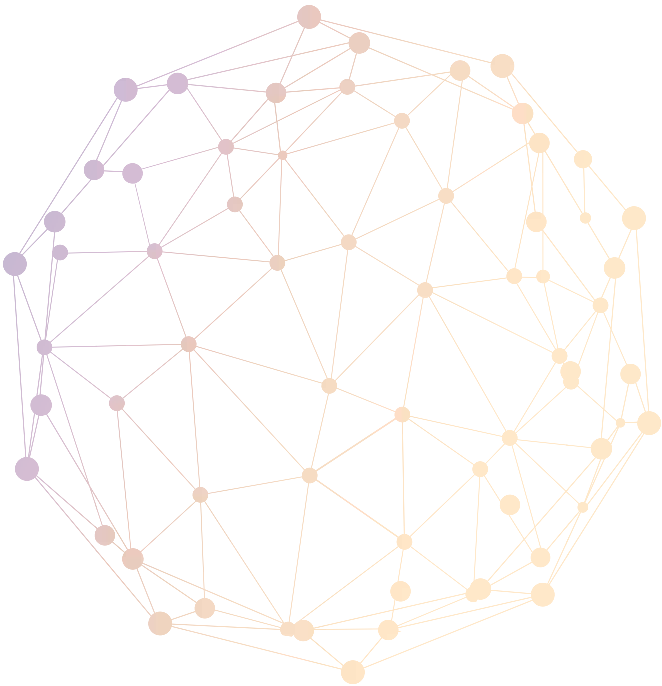


Permafrost peatlands with numerous lake depressions, Cape Bolvansky, Russia
Photo credit: Hans Joosten

Permafrost Peatlands:
Losing ground in a warming world

Accelerating change in the Arctic

Peatlands located in the tropics receive much attention as global hotspots for their critical role in carbon storage and climate change mitigation. They store nearly 120 gigatons of peat carbon, but this is only about 20 per cent of all carbon locked away in global peatlands.[1] The largest volumes are stored in the northernmost areas of our planet, with the northern circumpolar region holding almost half of the world's soil organic carbon, largely in the form of permanently frozen peat.[2-5]

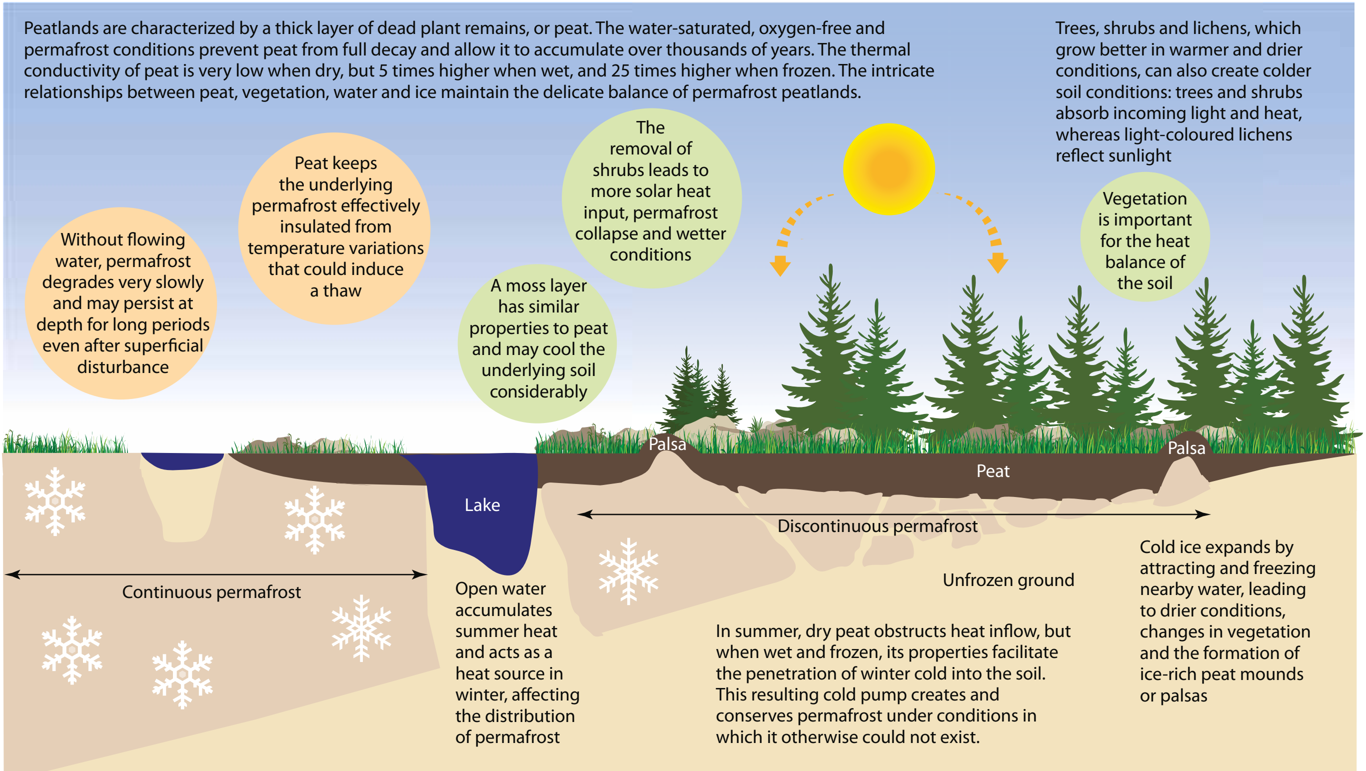
Much of the ground in the northern hemisphere freezes and thaws seasonally, and some stays frozen all year round. Underneath roughly 23 million square kilometres of the north lies permafrost – ground that remains at sub-zero temperatures for at least two consecutive years. Arctic and subarctic peatlands exist within the permafrost zones of Canada, Denmark/Greenland, Finland, Norway, Russia, Sweden and the United States. Permafrost peatlands with a peat layer thicker than 40 centimetres span over 1.4 million square kilometres, and an even larger area has shallower peat.[3,6-8] Extensive permafrost peat deposits can also be found far outside the Arctic and subarctic regions, for instance in Mongolia and on the Qinghai-Tibetan plateau, where mountain ranges prevent warm oceanic air from moving inland, and winter temperatures are very low.[9,10]

Permafrost peatlands are undergoing rapid changes. The Arctic is now warming twice as fast as the global average.[11] In recent decades, the southern permafrost boundaries have receded northwards by 30 to 80 km, a significant loss in coverage.[12-15] The risks associated with permafrost degradation are that the mobilization and microbial decomposition of previously buried, frozen organic matter could lead to the release of significant amounts of carbon dioxide and methane, which could, in turn, strongly reinforce global warming.[16-19] Widespread permafrost degradation would also have enormous direct impacts on the regions' ecosystems, hydrology and infrastructure.

Although permafrost has been intensively studied for over a century, more research on its distribution, characteristics and dynamics is critically needed to better understand how it responds to climate change and human disturbance.[20] In the case of peatlands with permafrost, knowledge is even more incomplete. The way in which permafrost peatlands respond to a warming climate and their collective role in global climate change are neither clearly understood nor straightforward, as the interaction of permafrost, ecosystems and climate is extremely complex.[20-22] For example, although frozen (dry) and thawed (wet) peatland sites may have similar carbon-sequestration rates and act as a carbon sink, they usually have totally different greenhouse-gas flux characteristics and may act as a net source of emissions.[23-25] Moreover, frozen and thawed peatland sites could also rapidly alternate over time and space.[23,26]

Permafrost thaw is seen as one of the most important "tipping elements" that could precipitate a runaway greenhouse effect, or an uncontrollable "Hothouse Earth".[27] To avoid such a destructive scenario, it is critical that the world's permafrost and its peatlands stay frozen and retain their carbon deposits.

Peatlands and permafrost: the role of peat, plants and water



Thawing permafrost, decaying peat and complex interplays

Each year of the past decade has been warmer in the Arctic than the warmest year of the 20th century.[15] Globally, permafrost temperatures have continued to rise in recent decades. The greatest increments in annual mean permafrost temperatures have been observed in the coldest parts of the Arctic, whereas the increases have been much less in "warmer" permafrost and in discontinuous permafrost zones. In some locations, permafrost temperatures have dropped marginally because of recent cold winters.[15,28]

As temperatures rise, the thawing of ice-rich permafrost or the melting of ground ice leads to distinctive depressions in the landscape, known as thermokarst. Over the past decades, thermokarst formation in peatlands seems to have accelerated in the discontinuous permafrost zones.[29-31] However, across the Arctic, long-term observations do not suggest uniform trends in thermokarst development attributable to global warming.[15]

When formerly frozen soil collapses due to a thaw, the subsidence allows the formation of small, new bodies of water that can later evolve into lakes. The formation of thermokarst lakes, in turn, accelerates permafrost thaw even faster and deeper.[19] The spread of these lakes, on the other hand, could also increase the connectivity of drainage networks, supporting lake drainage, vegetation regrowth, peat formation and the re-establishment of permafrost.[32-37] These contrasting dynamics illustrate the greater need for a better understanding of potential impacts of the warming trend.

Video: Permafrost – what is it?

Video link: https://www.youtube.com/watch?v=lxixy1u8GjY
Photo: Freshly-drilled core sample of permafrost, Pokhodsk, Russia
Photo credit: Hans Joosten
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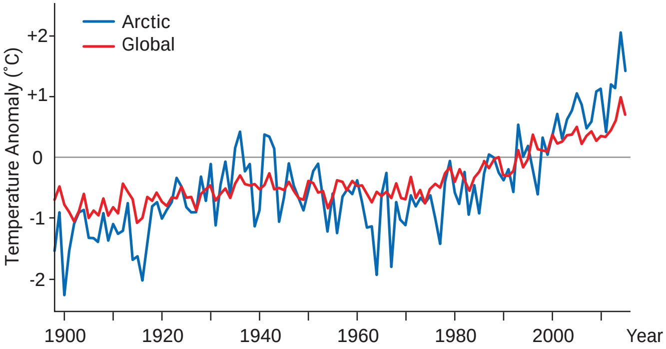
Arctic (60–90°N) and global annual surface air temperature relative to the 1981–2010 average value



Source: Adapted from the Arctic Report Card 2018 of the US National Oceanic and Atmospheric Administration[11]

Climate change and elevated temperatures have dramatically increased the incidence of wildfires in the Arctic, with blazes spreading into tundra and forest–tundra boundary regions. Fuelled by underlying peat deposits, fires release vast amounts of carbon, destroy vegetation and insulating soil layers, and decrease ground albedo, or light reflectance, leading to increased sensitivity to climate change and widespread thermokarst development.[38-44] Even under the most conservative scenarios, the combined impacts of warmer temperatures and wildfires are predicted to be especially severe in discontinuous permafrost zones, with climate conditions becoming unfavourable to permafrost altogether.[31] This could cause changes in the types of vegetation and its productivity, which could in turn result in larger and more frequent wildfires.[45,46]

Another effect of increased warming due to climate change is that permafrost thaw could release significant amounts of methane, a potent greenhouse gas, into the environment. Although there is large variability in Arctic methane-emission estimates, current global climate projection models seem to suggest only slight increases in methane emissions from the northern permafrost region.[47,48] However, most models do not include an adequate representation of thaw processes.[8]

Thermokarst

Photo credit: Hans Joosten

Thermokarst is a landscape feature that results from the melting of ground ice in regions with underlying permafrost, causing subsidence at the surface. Typical thermokarst formations include thermokarst lakes, sinkholes, pits and troughs in polygonal terrain.[56,57] Thermokarst is widespread in discontinuous permafrost zones.[58,59] It is also frequently found in the much colder zones of continuous permafrost, where ice wedges cause permafrost instability.[60,61]

Water accumulating due to thermokarst initially enhances heat gain and degradation in a positive feedback. Conversely, vegetation growth and the accumulation of organic matter gradually limits further downward thawing. Because of new and rapid peat accumulation in thermokarst depressions, the thawing of permafrost does not necessarily convert the peatland into a carbon source.[22,23,62] However, wet soil conditions will likely cause the release of methane.

A recent modelling study assessed the long-term climatic consequences of permafrost degradation by considering the abrupt thaw processes relating to recently formed thermokarst lakes. The result suggested that within this century, carbon release in the form of methane (CH_4) may account for a small fraction of total carbon release from newly thawed permafrost, yet it could cause up to 40 per cent of the additional warming effect attributable to newly thawed permafrost.[49]

Climate change is only one of many factors directly influencing the changes in permafrost peatlands. Any disturbance to the surface soil can lead to permafrost degradation, including natural processes such as forest or tundra fires, and anthropogenic disturbances, such as industrial and urban infrastructure development and construction activity, mining, tourism, and agriculture.[50,51] These many forms of development in permafrost peatlands often disregard the unique features of the areas, causing landscape fragmentation and disruption of the water cycle.[14,52] In Russia, 15 per cent of the tundra territory has been destroyed by transport activities, resulting in permafrost thawing, erosion, subsidence and thermokarst development.[53] About 45 per cent of the oil and natural gas production fields in the Russian Arctic are located in the most ecologically sensitive areas, often in peatlands, including the Pechora region, Polar Urals and north-west and central Siberia.[54,55] The rising demand for natural resources and increased accessibility to frozen regions due to warmer conditions may in the future result in more industrial and infrastructural activity, escalating disturbance to peatlands and permafrost. The resulting changes will also impact indigenous peoples who have traditionally depended on the use of land such as peatlands for food, reindeer, game, and fish.[14]

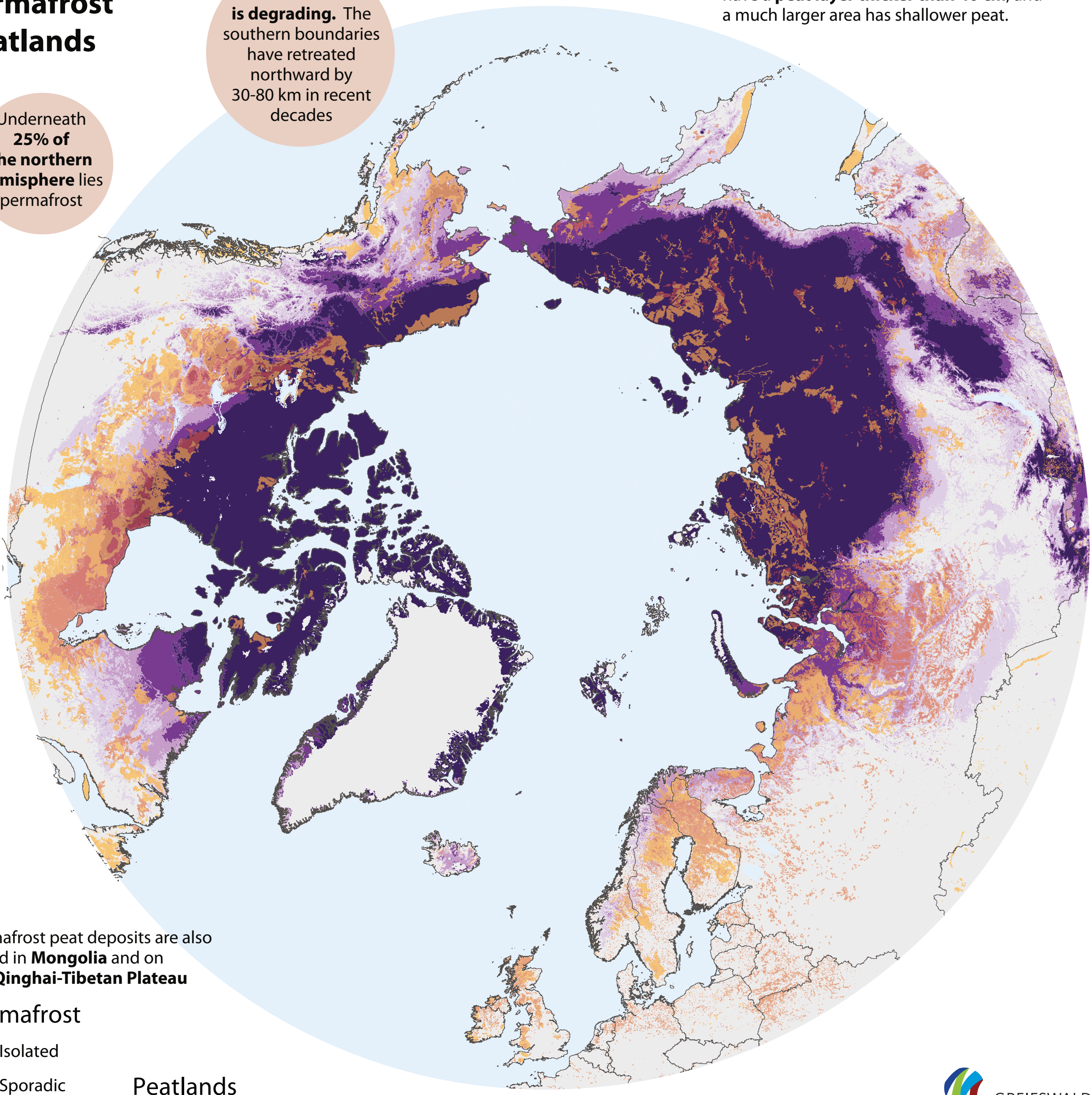
Thawing and collapse of permafrost in Mongolia *Photo credit: Hans Joosten*

Distribution of Permafrost Peatlands

Peatlands span vast areas in the permafrost zones. At least **1.4 million km^2** of permafrost peatlands have a **peat layer thicker than 40 cm**, and a much larger area has shallower peat.

Permafrost is degrading. The southern boundaries have retreated northward by 30-80 km in recent decades

Underneath **25% of the northern hemisphere** lies permafrost



Permafrost peat deposits are also found in **Mongolia** and on the **Qinghai-Tibetan Plateau**

Permafrost

- Isolated
- Sporadic
- Discontinuous
- Continuous

Peatlands

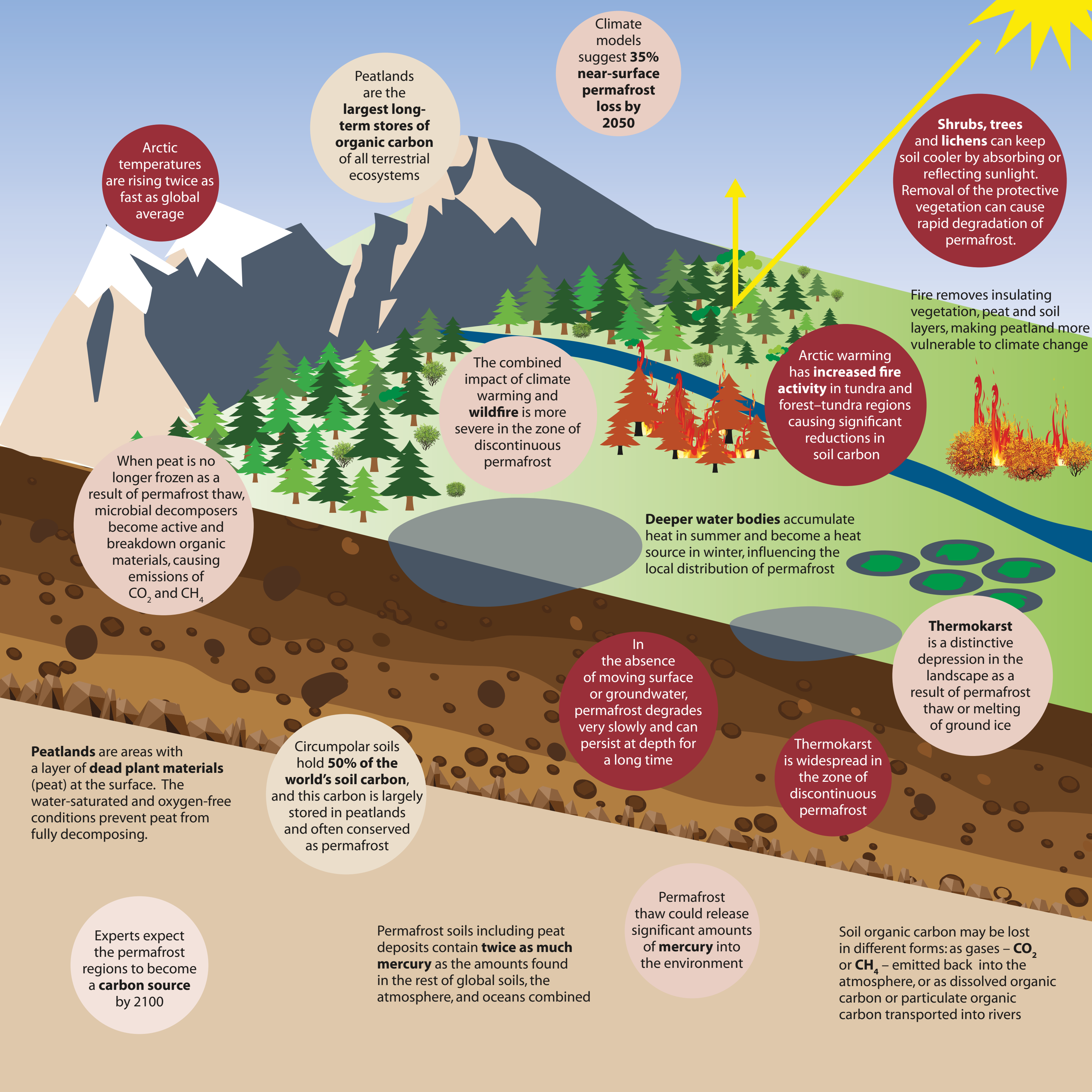
- > 50% cover
- 20-50% cover

GREIFSWALD MIRE CENTRE

Geospatial data sources:

Peatlands data provided by Greifswald Mire Centre, Greifswald, Germany

Permafrost data provided by Alfred Wegener Institute, Helmholtz Center for Polar and Marine Research (AWI), Bremerhaven, Germany[90]



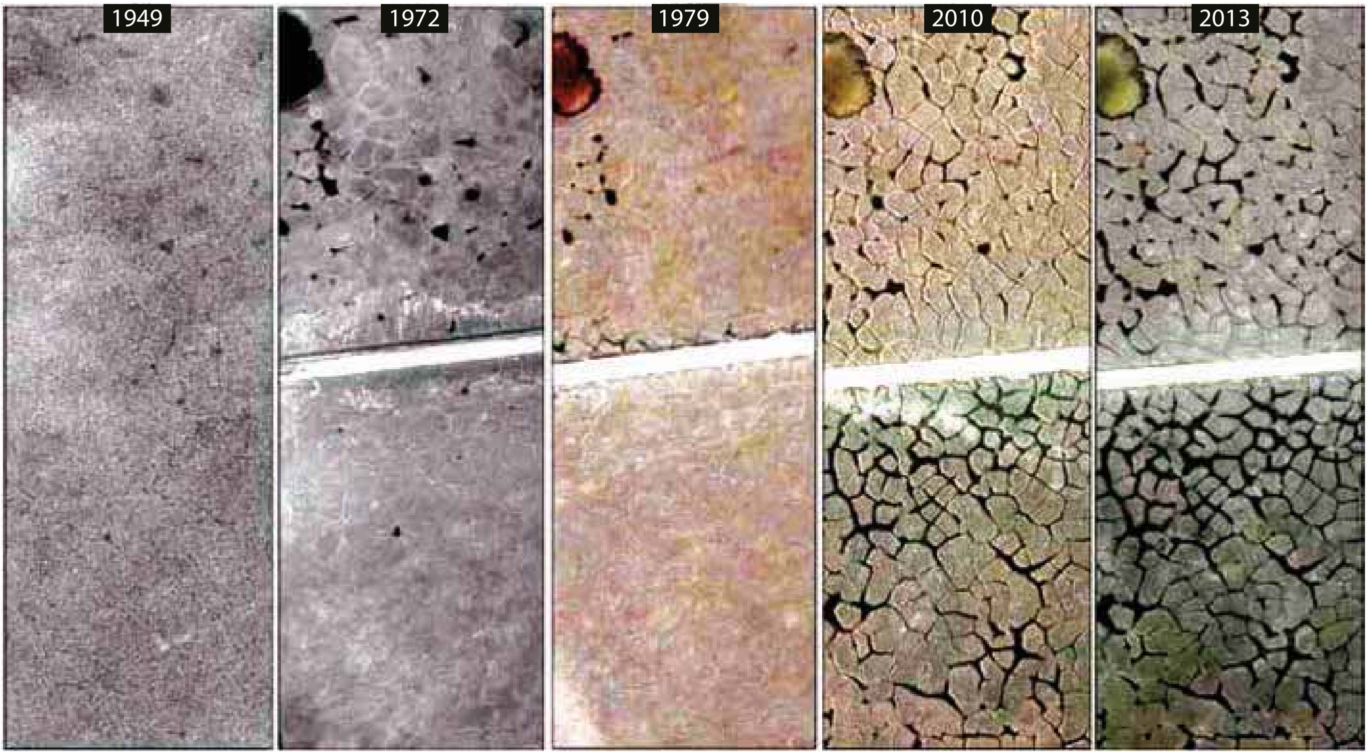
Arctic temperatures are rising twice as fast as global average
Peatlands are the **largest long-term stores of organic carbon** of all terrestrial ecosystems
Climate models suggest **35% near-surface permafrost loss by 2050**
Shrubs, trees and **lichens** can keep soil cooler by absorbing or reflecting sunlight. Removal of the protective vegetation can cause rapid degradation of permafrost.
Fire removes insulating vegetation, peat and soil layers, making peatland more vulnerable to climate change
The combined impact of climate warming and **wildfire** is more severe in the zone of discontinuous permafrost
Arctic warming has **increased fire activity** in tundra and forest–tundra regions causing significant reductions in soil carbon
When peat is no longer frozen as a result of permafrost thaw, microbial decomposers become active and breakdown organic materials, causing emissions of CO_2 and CH_4
Deeper water bodies accumulate heat in summer and become a heat source in winter, influencing the local distribution of permafrost
Thermokarst is a distinctive depression in the landscape as a result of permafrost thaw or melting of ground ice
In the absence of moving surface or groundwater, permafrost degrades very slowly and can persist at depth for a long time
Thermokarst is widespread in the zone of discontinuous permafrost
Peatlands are areas with a layer of **dead plant materials** (peat) at the surface. The water-saturated and oxygen-free conditions prevent peat from fully decomposing.
Circumpolar soils hold **50% of the world's soil carbon**, and this carbon is largely stored in peatlands and often conserved as permafrost
Experts expect the permafrost regions to become a **carbon source** by 2100
Permafrost soils including peat deposits contain **twice as much mercury** as the amounts found in the rest of global soils, the atmosphere, and oceans combined
Permafrost thaw could release significant amounts of **mercury** into the environment
Soil organic carbon may be lost in different forms: as gases – CO_2 or CH_4 – emitted back into the atmosphere, or as dissolved organic carbon or particulate organic carbon transported into rivers

Growing awareness of permafrost peatlands

For more than a century and increasingly over the last decades, permafrost regions have been the subject of research and technology development to address their distinctive scientific and engineering challenges. Despite the efforts of the International Permafrost Association and the Global Terrestrial Network for Permafrost, large gaps in region- and habitat-specific knowledge remain, not least due to extreme climatic conditions, limited accessibility and a complex geopolitical setting. A recent review indicated that 30 per cent of all citations in scientific literature related to field experiments in the Arctic are primarily derived from the direct surroundings of just two research stations: Toolik Lake in Alaska, USA and Abisko in Sweden.[63] This could bias scientific consensus and lead to inaccurate predictions of the impacts of climate change in the Arctic.

With the growing awareness of climate change and Arctic ice melt, recent assessments are increasingly trying to encompass aspects such as social-ecological change, regime shifts, and the role of human action in adaptation and transformation.[64,65] Large-scale research projects are being developed to address the implications of permafrost thaw and degradation. These include the Arctic Development and Adaptation to Permafrost in Transition (ADAPT) initiative, which collaborates with 15 laboratories across Canada and other groups of researchers to develop an integrated Earth systems science framework in the Canadian Arctic. Dedicated laws such as Ontario's 2010 Far North Act are combining with new planning initiatives to open up and protect the Far North through a land-use planning process in consultation with First Nations.[66]

The Arctic Council is an example of strong international cooperation that has been especially instrumental in



Progression of thermokarst development due to permafrost thaw between 1949 and 2013 in a study site located in Prudhoe Bay, Alaska, United States. The white line is the Spine Road constructed in 1969.

Source: Walker et al. (2014)[52]

generating and increasing knowledge for national and international policymaking, such as with its 2017 report on snow, water, ice and permafrost in the Arctic.[15,67] While it is recognized that Arctic states play a key role as stewards of the region, efforts by other actors in the protection and awareness of permafrost peatlands are also needed. A number of international organizations, such as the Intergovernmental Panel on Climate Change – through its IPCC Special Report on the Ocean and Cryosphere in a Changing Climate, the World Meteorological Organization, and the International Science Council through the International Arctic Science Committee, have become increasingly engaged, helping to raise awareness and understanding of the implications of changes in the Arctic.

Permafrost thaw has led to thermokarst formation in peatlands near Naryan-Mar, Nenets autonomous region, Russia

Photo credit: Hans Joosten

Ontario's Far North Act and the role of First Nations in protecting permafrost peatlands

Between 50-57 °N and 79-94 °W lies the **Far North of Ontario**, Canada – a dynamic landscape hosting arctic, boreal, and temperate biomes. Here, peatlands dominate the landscape, covering 47 per cent or 21 million hectares of the Far North area, and storing about 36 gigatons of carbon as peat.[68] This is equivalent to a quarter of the carbon stored in all of Canada's peatlands.

Assented to in October 2010, **Ontario's Far North Act** recognizes the significant role of the Far North in carbon storage and sequestration capacity, and provides for community-based land-use planning as a strategy to fight climate change.[66,69] The Act centres around the significant role of First Nations – aboriginal peoples in Canada who are not Métis or Inuit – in land-use planning that includes cultural, social, ecological and economic considerations.

As required by the Act, the **Far North land use strategy** sets out to help prepare community-based land-use plans while integrating issues beyond the scope of individual planning areas, such as indigenous knowledge. Four objectives outlined in the strategy include:

1. A significant role for First Nations in planning.
2. The protection of ecological systems and areas of cultural value in the Far North by including at least 225,000 km^2 of the region in an interconnected network of protected areas designated in community-based land-use plans.
3. The maintenance of biological diversity, ecological processes and functions, including the storage and sequestration of carbon in the Far North.
4. Enabling sustainable economic development that benefits the First Nations.

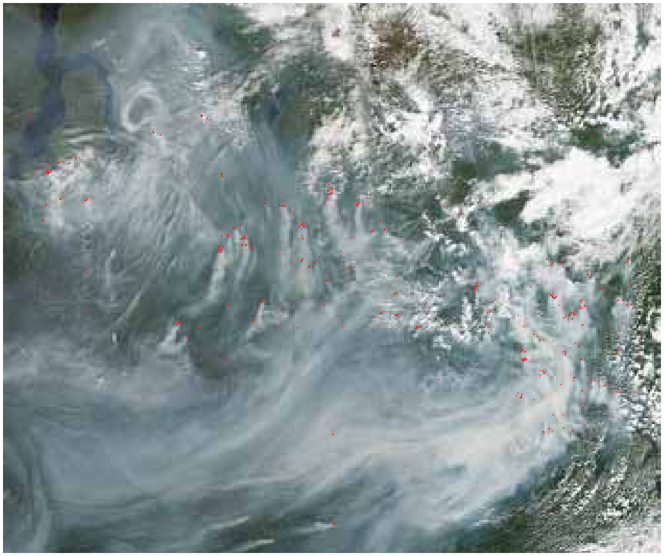
The strategy was planned for completion by 2016, but the process is still ongoing, led by interested First Nations working with the Ontario Ministry of Natural Resources and Forestry. Some community-based land-use plans have been approved, some drafted, while others are underway and some have not yet started.[70] Although progress is being made, uncertainty remains on how to achieve some of the Act's objectives, including in areas of governance, and particularly in scientific knowledge. It is imperative to understand how climate change affects carbon sequestration and storage in the Far North peatlands, as well as the related ecological processes, in order to develop appropriate policy and management responses.

Knowledge priorities and network expansion

There remains a great deal of uncertainty about how fast permafrost peatlands will change and what the impacts of those changes will be, both locally and globally. International cooperation is required to fund further research in the long term and devise workable strategies to reduce vulnerabilities. Nations need to collaborate on a range of implementable measures that acknowledge and apply traditional and local knowledge, facilitate engagement with stakeholders, and develop effective observation networks.[15] At the same time, public outreach and education concerning the risks, likely impacts and potential adaptation options will be key to developing informed governance and policy.

Although there is an existing network of observation stations providing information on general trends in permafrost change, the spatial distribution of sites is very uneven. In particular, there are large gaps in the network across the central Canadian and central Siberian Arctic, Greenland, Russian Far North-East, Tibetan Plateau and subarctic region.[30,63] The timely assessment of the global status of permafrost requires the expansion of existing research networks to a more comprehensive monitoring network. This extended network would optimally be designed to be user-friendly for all stakeholders, from climate scientists to the general public, and would include the use of standardized measurements and easily accessible databases.[15,64] Countries with extensive permafrost zones would benefit from preparing adaptation plans that assess the potential risks and include mitigation strategies for the damage and costs of permafrost degradation.[64]

Permafrost peatlands as carbon hotspots represent a special, highly diverse and dynamic environment that encompasses complex relationships between soil carbon, hydrology, permafrost, vegetation, and people. The major knowledge gaps lie in the limited understanding of how the processes interrelate and in the insufficiency of current studies and models. More research is required on the precise location of permafrost peatlands, how they are changing, and what their release potential is. Climate models need to include carbon emissions from the mobilization of permafrost carbon. To better characterize the response and feedback of permafrost peatlands to climate change, it will be critical to advance beyond single-disciplinary investigations. This will require



Satellite image taken on 19 July 2016 showing dense smoke over permafrost peatlands of north-central Russia. Red demarcations indicate high surface temperatures likely caused by peat fires.
Photo credit: NASA Earth Observatory/Jesse Allen and Joshua Stevens

Video: Restoring peatlands in Russia for fire prevention and climate change mitigation

Video link: https://www.youtube.com/watch?v=QZ5qu_nPHYM *© Wetlands International*
Photo: Fire in dwarf birch tundra in Komi Republic, Russia *Photo credit: Hans Joosten*

Video: Peatlands – climate regulation and biodiversity

Video link: https://www.youtube.com/watch?v=ZcxZ9gvNfSU © Naturstyrelsen

Flat palsas in Komi Republic, Russia

Photo credit: Hans Joosten

a move towards an integration of field observations and retrospective – or palaeoenvironmental – studies, remote sensing, and dynamic modelling.[22,30] The physical complexity of permafrost peatlands and the significant potential risks of their degradation and disruption also demand a more holistic approach to land-use planning and management, requiring better integrated knowledge for planners and policymakers.

The Arctic has already begun to change substantially. Even with the full implementation of the Paris Agreement under the United Nations Framework Convention on Climate Change, it is still likely that by the end of this century the Arctic environment would be quite different from that of today.[15] The near inevitability of accelerating impacts reinforces the urgent need for local and regional adaptation strategies targeting these carbon-dense northern ecosystems. The prudent management of permafrost peatlands will be key to limiting greenhouse-gas emissions, reducing human and ecological vulnerabilities, and to building longer-term climate resilience.

Palsa permafrost mire near Noyabrsk, Western Siberia, Russia

Photo credit: Franziska Tanneberger

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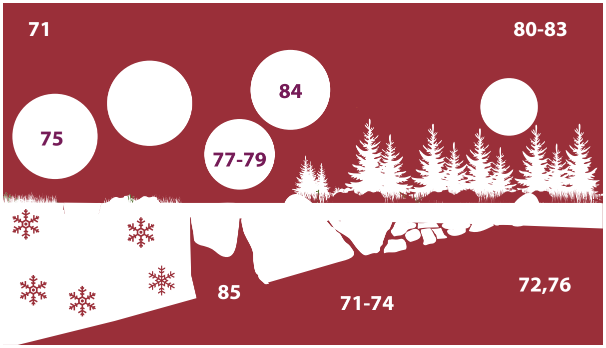

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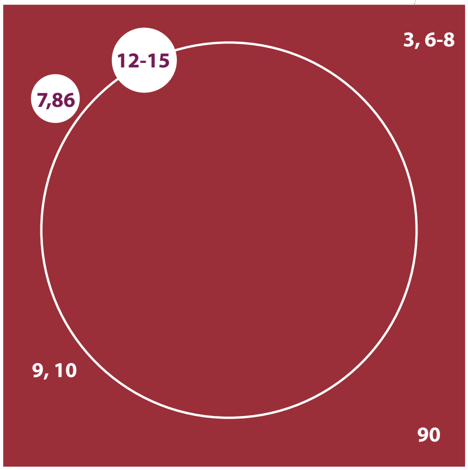

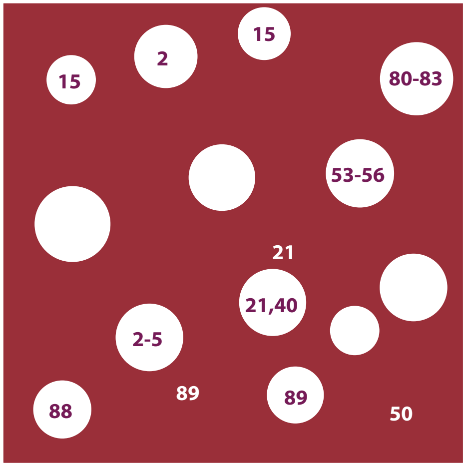

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