A Melting Planet: A review providing an overview of the current state of permafrost and its wide-ranging impacts on both society and the planet.

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Abstract

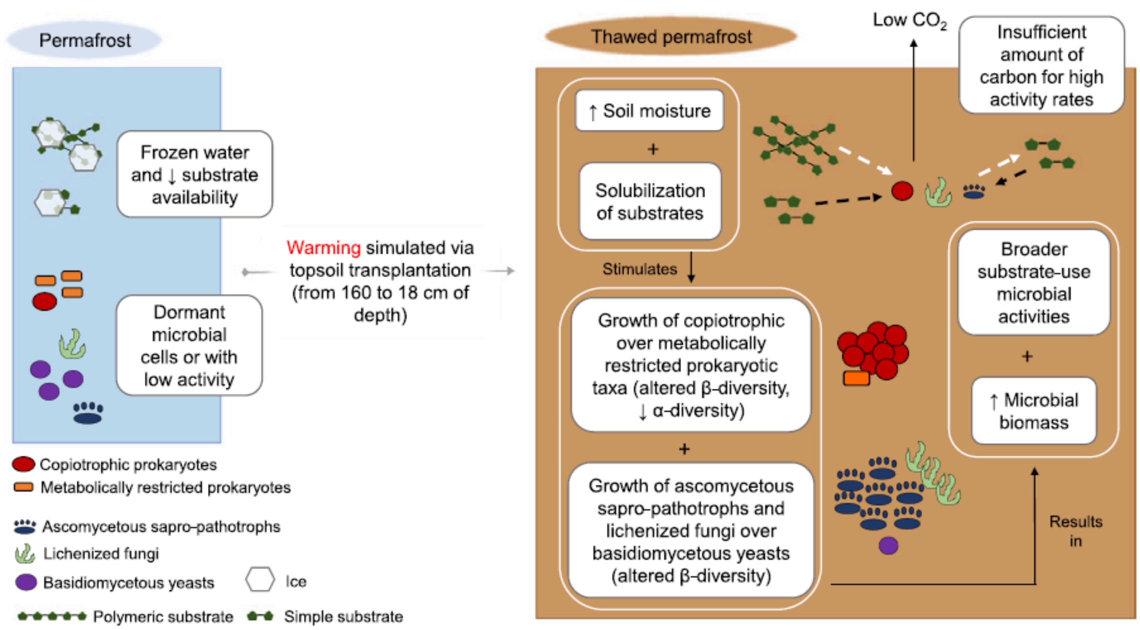
This literature review investigates the effects of thawing permafrost on infrastructure and the environment. The paper explores how thawing permafrost causes soil shifting and damage to infrastructure such as buildings, roads, and pipelines. Furthermore, the review investigates how trapped greenhouse gases, such as methane and carbon dioxide, released by thawing permafrost, will contribute to climate change. Additionally, this review discusses the existence of previously unknown and unexplored microbiomes frozen in permafrost, which may have serious implications for human and environmental health. Overall, the goal of this literature review is to provide a thorough understanding of the effects of permafrost thaw and to identify areas for future research in this field.

Keywords: permafrost, infrastructure, microbiome, greenhouse gas emissions, climate change

Introduction

Climate change

All over the world, the effects of climate change are being felt to varying magnitudes. Every year, the average surface temperature of the planet increases by a fraction of a degree (Lindsay, 2023). This slight increase in temperature goes unnoticed. However, when it continues for years, extreme climate change events occur. The revolutionary design of the greenhouse is amazing and efficient, but not when it causes the degradation of our planet. The sunlight warms up the planet, and when the warmth attempts to escape, gases such as the carbon dioxide in the atmosphere trap it which causes an increase in temperature. This leads to major events, such as glaciers melting and an increased number of severe storms and droughts. Additionally, as glacier ice melts, the water is deposited into the ocean, causing it to grow, warm, and change in pH. All these changes have a great effect on the ecosystem and its inhabitants, including many species that are now going extinct. The figure below by Perez-Mon et al. demonstrates the warming of the permafrost soils and their effects on alpine microbial communities and ecosystems (2022).



Permafrost

Permafrost is a frozen soil layer that covers a significant portion of the Earth's land surface. Its degradation due to warming temperatures may have significant consequences for the environment and human societies. According to the Canadian Permafrost Association, permafrost is a type of ground that has been frozen at 0°C or lower for at least two years. Permafrost can be found throughout northern areas and at high elevations in mountainous regions such as the Rocky Mountains in Canada and Siberia.

In addition to permafrost, there is also a layer of soil just beneath the surface that thaws in the summer and refreezes in the winter. This layer is known as the active layer, and in Canada, it typically ranges in thickness from 0.5 meters to 2 meters. In permafrost regions, the layer immediately beneath the active layer is generally permafrost. However, there may be an intervening layer known as a talik, which remains above 0°C throughout the year. The existence of a talik is often an indication that the permafrost is degrading.

Discussion

Shifting soil and vulnerable infrastructure

A physical effect of permafrost melting is the shifting and melting of the frozen soils. As the soils melt, there are massive changes to the soil structure (EPA 2021). These shifts come from the melting of the water that is frozen solid as ice and supports the soil above or beside it. Without the support of the ice and other frozen structures, the buildings and towns built on top of these areas experience immense crumbling. There are many towns built completely on top of these permafrost regions and are now suffering the effects of this melting.

Due to this crumbling, there are small actions that can be taken to prevent this melting and deterioration of the infrastructure. These can include raising parts of the homes to stabilize them or even installing a cooling system in the soil. However, this is not affordable for everyone and is causing a housing crisis. This unaffordability causes the marginalization of the poor and, in turn, causes homelessness (Schreiber 2018). Homelessness is experienced in a variety of ways but is prevalent in these areas affected by the melting of the soils.

The potential relocation of towns is looming due to the high level of melting, which is uncertain for the future. Therefore, many people are having to relocate their homes and families to ensure their safety and financial security. This issue has consumed many resources in terms of research and short- and long-term solutions.

Greenhouse gas emissions

Permafrost soils are a significant carbon store globally, holding approximately 60% of Earth's terrestrial carbon, which is more than twice the amount currently stored in the atmosphere. However, the warming climate is causing the temperature of permafrost to increase worldwide, rendering immense carbon stores vulnerable to accelerated microbial decomposition and risking loss as greenhouse gases. This permafrost-carbon feedback is considered one of the most important biogeochemical feedbacks to future climate change.

Carbon losses in permafrost soils are influenced by environmental conditions, primarily temperature and soil moisture conditions, which regulate the reaction kinetics of decomposition. Studies by Anisimov and Zimov (2020) and Treat et al. (2014) have looked at how temperature affects carbon emissions and observed that temperature is a key factor in permafrost changes, specifically greenhouse gas emissions. Treat et al. found that the temperature of incubation had a strong effect on carbon emissions,

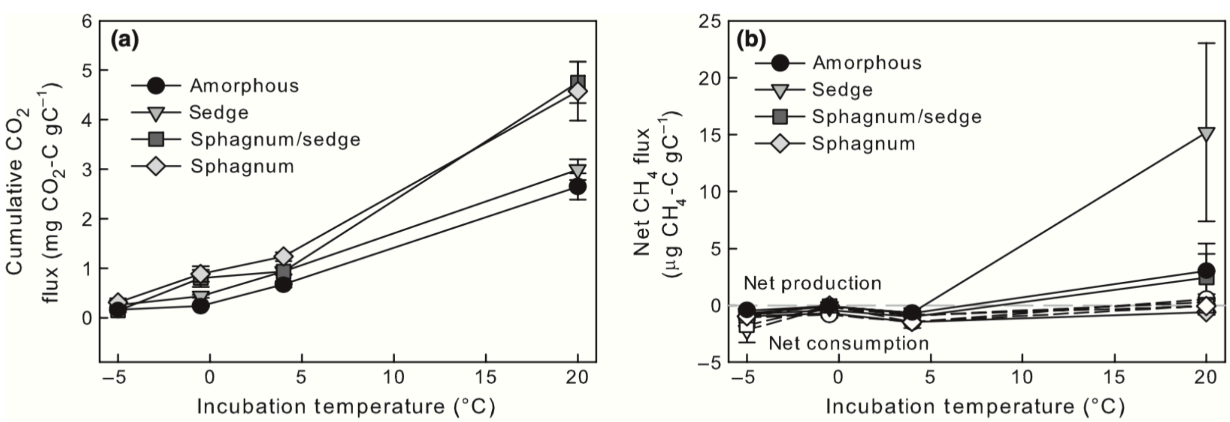


Fig. 1 (a) Cumulative CO_2 and (b) net CH_4 emissions over the 30 day incubation experiment under aerobic conditions. In panel (b), filled symbols represent active layer emissions, while permafrost samples are open. Error bars represent standard error.

indicating that decomposition in these ecosystems is strongly temperature dependent. This is demonstrated by the image above (Treat et al., 2014). The total amount of CO_2 or CH_4 emitted over the 30-day incubation period increased significantly with temperature as illustrated above.

The study went on to describe the importance of temperature variation and microbial respiration and how it affects carbon release. They found significant differences between aerobic and anaerobic treatments at 20°C but no differences at 0.5°C, most likely due to the lower temperatures limiting microbial respiration. Regarding carbon release into the atmosphere, the observations of Anisimov and Zimov in Cherskiy raise concerns that in the absence of a mossy surface cover (2020), sustained deep thawing may occur due to the combined effects of climate change and microbial heating. Thawing may occur abruptly rather than gradually in this case. This could result in the rapid release of significant amounts of carbon, followed by microbial decomposition at a rate of up to 3% per year. While the release of carbon molecules following permafrost has a relatively large literature backing, the dynamic between carbon and other greenhouse gases is more limited. Dieleman et al. (2022) explored the carbon and nitrogen relationship following thaw. The research has shown that increasing bioavailable nitrogen species like NH_4^+ may prompt microbes to utilize carbon more efficiently for biomass production, limiting soil carbon mineralization. They concluded that after permafrost thaw, in deep soil with limited carbon stores, the initial burst of available resources following thaw is short-lived. In contrast, in shallow soil with larger but tougher resources, CO_2 production is higher due to microbial activity. The study suggests that although the most vulnerable carbon stocks are deep in the soil, warming of larger stocks closer to the surface may have a bigger impact over the long-term. This study highlights the need to consider both depth and thaw history when assessing the effects of permafrost thaw on carbon and nitrogen cycling.

Unresearched microbiome

Bacteria and other microorganisms exist all around us and play a crucial role in our bodies and environment. These everyday bacteria are extensively studied by researchers, with studies being conducted on their infectivity, lethality, severity, and how to exterminate them if necessary. This allows for the classification of each microorganism and grouping based on the data collected.

In permafrost soils, however, there have not been many studies on the bacteria that are present. This ecosystem was completely isolated from the active ecosystem and not deemed a priority for many researchers in the world. However, with the increased interaction with these ecosystems, there will be a need for more research on these mysterious microorganisms. This ecosystem is completely frozen year-round, yet there are still bacteria able to live in these conditions and utilize this inactive carbon.

These harsh environments, resembling extraterrestrial conditions, would cause many of our common microorganisms to die and be unfit for their environment. Adapting to a climate change approach, the varying metabolisms and activity of these bacteria is innovative and fascinating since they are unlike any of the previously known bacteria and other microorganisms. By studying these microorganisms, we can understand the manner in which greenhouse gases are synthesized and degraded, which could help fight against global warming.

The rapidly thawing permafrost in the Arctic has the potential to release antibiotic-resistant bacteria or undiscovered viruses, both of which pose a threat to our society. On the other hand, there is also the possibility of bacteria with amazing applications for our society. However, both of these possibilities require further investigation and research before being demonstrated.

Conclusion

In conclusion, permafrost thawing has a significant impact on soil disruptions and shifts. As permafrost thaws, societies built on permafrost lands will be forced to find solutions to the altering terrain. Additionally, permafrost melting is releasing large amounts of greenhouse gases into the atmosphere, exacerbating climate change and encouraging microbial activity. The potential impact of the microbiome frozen in permafrost on global ecosystems is still largely unresearched, and more attention should be given to understanding how thawing permafrost may affect the release and behavior of microbes. Given its critical role in maintaining environmental stability, permafrost warrants further research to ensure sustainable conditions for society.

Recommendations

Areas vulnerable to altered climate

The ozone layer is a gas layer that protects the earth from the sun's ultraviolet rays. Due to human activity, the ozone layer remains vulnerable to human disturbances and environmental changes. The impact of thawing permafrost on the ozone layer is unknown and is a knowledge gap in current scientific literature. Some scientists believe that the release of greenhouse gases from permafrost could trigger a feedback loop that accelerates climate change, leading to further ozone depletion. Others believe that the ozone layer will be unaffected. Therefore, more research needs to be conducted to ensure the preservation of our protective layer.

Microbiome analysis

The plethora of microbes present in the permafrost is of great importance for the uncertain future ahead. Studying permafrost microorganisms can provide valuable insights into the functioning of Arctic ecosystems, the impacts of climate change, and the development of new biotechnologies. The activity of these microbes is key in the release and consumption of the great amount of carbon locked away in the permafrost that is now turning into active carbon in the ecosystem. There can also be possible bioremediation applications of these microbes since they are closely tied to climate change and the release of carbon from permafrost. These microorganisms deal with a completely diverse and unknown environment and could produce new and highly useful metabolites such as antibiotics. This microbiome has also been isolated for years and may contain viruses and other organisms that have extreme adaptations that can aid in the understanding of extreme metabolisms and potential extraterrestrial applications. Through the further study of these organisms, a deeper understanding can be applied to reverse climate change or aid in other unrelated fields of great importance.

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