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INVITED COMMENTARY

Winter, the forgotten season

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Seasonality plays an essential role in shaping the life histories of organisms. In northern high-latitude areas, that is, the boreal and Arctic regions, spring, summer, autumn, and winter all represent distinct periods in the ecosystem's annual cycle. In these areas, winter is the longest of the four seasons, and in many ways the most influential season for both aquatic and terrestrial ecosystems (Berge et al., 2020; Campbell et al., 2005; Marchand, 2014). Typically, the highest mortality in the population occurs during winter, strongly affecting population dynamics and individual fitness. Yet, successful overwintering is not solely a matter of survival but may have both direct and indirect effects on reproductive success (Campbell et al., 2005; Marchand, 2014). For example, the breeding season for many ungulates takes place in autumn, and the females are pregnant during the winter months. Producing living, viable offspring in the following spring depends on the mother's ability to cope with the harsh winter conditions. Meanwhile, winter conditions can also have far-reaching effects on the whole ecosystem. For instance, bilberry (*Vaccinium myrtillus*) is an essential keystone species in boreal forest ecosystems. In winter, the snow cover protects bilberries from drying. Poor snow conditions are detrimental for the plant, with a knock-on effect on flower and berry production the following spring and summer (Tahkokorpi et al., 2007). This, in turn, affects several species dependent on bilberries, such as bumblebees, which are the key pollinators in many ecosystems. In the North, winter acts as a strong selection pressure, and successful adaptations are needed to survive and thrive in these winter-dominated ecosystems (Gudex-Cross et al., 2022; Marchand, 2014; Williams et al., 2015). Indeed, the impact of winter to the whole northern ecosystem, humans included, is indisputable. Yet, in ecological research winter has always been the neglected, most understudied season.

When talking about winter, we cannot avoid talking about global climate change. Climate warming has been most pronounced in northern high-latitude areas, affecting especially winters, making them shorter, wetter, and more unstable. In many places, the time period with an intact snow cover is getting shorter or is vanishing altogether (IPCC, 2021). At the same time, the human impact on natural environments has never been higher, for example, in the forms of deforestation and marine pollution. Such fast, large-scale changes in climatic and environmental conditions are raising concerns about their possible consequences on northern ecosystems, now and in the future. Currently, the most observed effects and predicted scenarios include changes in species distribution, decreasing biodiversity, the spread of invasive species, and the emergence of zoonotic diseases (e.g., Altizer et al., 2013; Bellard et al., 2012; IPCC, 2021; Pecl et al., 2017). As ecosystem interactions are inherently complex, these effects are undoubtedly only the tip of the iceberg, and a catalyst for further, yet unanticipated events. Global climate change is considered to be the most serious threat to the planet, with the radically changing northern winters as one of the mainstages of this crisis, and still, winter remains to be the neglected and most understudied season in ecology.

In the opinion article presented in Global Change Biology by Dinh et al. (2023), they discuss the causes and effects of the scarcity of winter studies in ecological and evolutionary research and highlight the urgent need for advanced winter research with a focus on understanding the effects of multiple and often simultaneous global change-induced stressors to wintering organisms and ecosystems. To demonstrate the seasonal bias in experimental studies on multiple stressor effects in freshwater, marine, and terrestrial systems, the authors have synthesized and elaborately reviewed close to 200 articles, of which they then selected 167 most relevant field studies, and categorized them based on the season they were conducted. Unsurprisingly, the vast majority of the studies were conducted

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during spring and summer, with only a few winter experiments. In their paper, Dinh et al. (2023) draw a vivid picture of the manifold, multidimensional effects the anthropogenic stressors may cause on ecological responses in organisms and ecosystems, depending on the season. To guide future global change studies, the authors have listed and categorized different types of interactions between multiple anthropogenic stressors and winter. With examples on different mechanisms including different species and ecosystems, they discuss how winter might modify the magnitude, effect, or interactions of multiple anthropogenic stressors, but also vice versa, the way human-induced stressors are changing the intensity or effect of winter.

If the ecological relevance of winter is so pronounced in northern ecosystems, how come winter studies have such a low priority in ecological and evolutionary research? Historically, one of the main reasons is the "old fashioned" research culture where the breeding season is considered the most influential season for organisms and ecosystems from the ecological and evolutionary point of view, while winter is the dormant season with low biological importance. Furthermore, winter studies are often laborious, with lots of logistical and practical challenges due to winter conditions, such as low temperatures, snow, and ice. They are also risky, with a high chance of failure. Everyone who has conducted winter field studies knows that you always need a plan B, sometimes even C and D. With these attributes, winter research is really ill-fitted for the current research funding culture. The highly competitive, yet short, funding periods force researchers to focus on low-risk research questions and methods. The most successful research ideas are often applicable, with an obvious and immediate connection to human welfare, whereas winter research is considered as basic research with little applicable value.

In their closure, Dinh et al. (2023) discuss the urgently needed actions and recommended applications to promote, develop, and increase high-impact winter research, especially focusing on winter multiple stressor ecology and evolution. They stress the importance of combining different study methods, both in laboratory and in the field, as well as adopting new technologies and networks, such as real-time remote sensing, machine learning, and citizen science networks. They also encourage researchers to actively integrate their forces with global organizations such as The Intergovernmental Panel on Climate Change, The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, and The United Nations Environment Programme, to enhance the ability of these organizations to adopt the new findings to their conservation and management initiatives.

It is critical to understand the role of seasonality in different ecosystems. Integrating winter studies as a fundamental part of climate change research is crucial to enable us to prepare, adapt, and respond to the global climate change effects now and in the future.

AUTHOR CONTRIBUTIONS

Saana Sipari: Conceptualization; writing – original draft; writing – review and editing.

CONFLICT OF INTEREST STATEMENT

The author declare that there is no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed for the current article.

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