diversity

Editorial

Bryophytes in a Changing World: Understanding Distribution Patterns, Risks, and Conservation

Lukáš Číhal

Silesian Museum, Nádražní Okruh 31, CZ-746 01 Opava, Czech Republic; cihal@szm.cz

Bryophytes are a group of small, non-vascular plants that include mosses, liverworts, and hornworts. They are found in almost every terrestrial environment and play important roles in regulating the global carbon cycle and maintaining ecosystem stability. In particular, bryophytes play a crucial role in carbon sequestration, which is the process of removing carbon dioxide from the atmosphere and storing it in plant tissues. However, as global warming continues, bryophyte growth and productivity may decline due to changes in temperature, precipitation, and moisture availability, potentially leading to a reduction in the capacity of these plants to sequester carbon [1].

Global warming and climate change also have significant impacts on them [2]. As bryophytes are highly sensitive to changes in temperature and moisture levels [3], one of the most significant effects of global warming on bryophytes is the alteration of their distribution patterns [4]. As temperatures rise and precipitation patterns change, bryophytes can be forced to move to higher elevations or latitudes in search of suitable habitats [5].

Another impact of global warming on bryophytes can also be seen in the alteration of their physiology, because even though bryophytes are known to have high levels of desiccation tolerance [6], as temperatures rise, bryophytes are likely to experience increased rates of evapotranspiration, leading to decreased water availability and increased susceptibility to desiccation stress [7].

All this means that bryophytes are highly vulnerable to the impacts of global warming and climate change, which are likely to alter their distribution patterns, physiology, and ecological roles. Therefore, it is essential to monitor and conserve bryophyte populations to ensure their continued survival and their contribution to global ecosystem stability. For those purposes, SDM can be used to investigate the environmental factors that influence the distribution of bryophyte species and to predict how these species may respond to future changes in climate or land use.

However, there are also some challenges in modeling bryophytes. For example, one challenge of modeling bryophyte distribution is their small size and patchy distribution, which can make it difficult to accurately map their distribution at a large scale. Additionally, bryophyte species often have complex ecological requirements, such as specific microhabitats or associations with certain tree species, which may be difficult to capture in an SDM. Despite these (and other challenges), species distribution models (SDMs) have been successfully used to study the distribution of bryophytes in a variety of ecosystems.

We have many applications in ecology and conservation for SDMs, including identifying areas of high conservation value [8], understanding the potential impacts of environmental change on biodiversity [9], or predicting the spread of invasive species [10]. Among others, SDMs can also be used to inform management decisions [11], such as selecting sites for protected areas [12] or planning for species reintroductions [13].

The development of SDM has been driven by advancements in both statistical modeling techniques and the availability of environmental data. With the growth of open-access data repositories and the development of new software tools, SDM has become increasingly accessible and is now widely used in ecological research and management. In this context,

Citation: Číhal, L. Bryophytes in a Changing World: Understanding Distribution Patterns, Risks, and Conservation. *Diversity* **2023**, *15*, 647. https://doi.org/10.3390/d15050647

Received: 26 April 2023
Accepted: 7 May 2023
Published: 10 May 2023

the aim of SDM is to provide a framework for understanding the complex relationships between species and their environment.

SDMs typically use statistical or machine learning algorithms to model the relationship between species occurrences and environmental variables. Input data includes species occurrence records and environmental variables such as climate, topography, land use, soil characteristics, and others [14].

The basic outputs of SDMs are usually maps, which are valuable tools for understanding and predicting the distribution of species. The field of SDM has a rich history and, over the past several decades, has evolved dramatically, with the development of new statistical methods and the availability of large datasets of species occurrences and environmental variables [15].

Species distribution models are widely utilized in conservation biogeography, particularly in spatially explicit biogeographic models. These models are highly valued due to their ability to forecast potential range shifts for species and communities in response to climate change. As a result, SDMs can serve as a valuable tool for informing and guiding conservation management planning, including the development of collaborative transboundary conservation frameworks. It is no surprise that SDMs are the most popular method in this field [16].

SDM has become increasingly important in recent years, particularly in the context of climate change. As the earth's climate changes, species are likely to experience shifts in their geographic range and habitat suitability, and SDM can be used to model and predict these changes, which is essential for understanding the potential impacts of climate change on biodiversity and informing conservation and management decisions.

Climate change is expected to have profound effects on the distribution and abundance of species. Changes in temperature and precipitation patterns, as well as extreme weather events, are likely to result in shifts in the geographic range and habitat suitability of many species [17]. For example, some species may experience range contractions or even extinction, while others may expand their range into new areas. These changes can have cascading effects on ecosystem dynamics and ecosystem services, such as pollination and pest control [18]. SDM can be used to predict how species distributions are likely to shift under different climate scenarios [19]. This can help to identify areas of high conservation value, areas where species are likely to be at risk, and areas where invasive species may become more of a threat. SDM can also be used to inform conservation planning and management, such as identifying corridors or refugia for species that may be particularly vulnerable to climate change (see also [20]).

SDM has made significant advancements over the past few decades, and it continues to be an active area of research in ecology. With the ongoing development of new modeling techniques and the availability of increasingly sophisticated data, there are many potential future directions of SDM.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Douma, J.C.; van Wijk, M.T.; Lang, S.I.; Shaver, G.R. The contribution of mosses to the carbon and water exchange of arctic ecosystems: Quantification and relationships with system properties. *Plant Cell Environ.* **2007**, *30*, 1205–1215. [CrossRef] [PubMed]
2. Turetsky, M.R. The role of bryophytes in carbon and nitrogen cycling. *Bryologist* **2003**, *106*, 395–409. [CrossRef]
3. Gignac, L.D. Bryophytes as indicators of climate change. *Bryologist* **2001**, *104*, 410–420. [CrossRef]
4. Zanatta, F.; Engler, R.; Collart, F.; Broennimann, O.; Mateo, R.G.; Papp, B.; Muñoz, J.; Baurain, D.; Guisan, A.; Vanderpoorten, A. Bryophytes are predicted to lag behind future climate change despite their high dispersal capacities. *Nat. Commun.* **2020**, *11*, 5601. [CrossRef] [PubMed]
5. Steinbauer, M.J.; Grytnes, J.A.; Jurasinski, G.; Kulonen, A.; Lenoir, J.; Pauli, H.; Rixen, C.; Winkler, M.; Bardy-Durchhalter, M.; Barni, E.; et al. Accelerated increase in plant species richness on mountain summits is linked to warming. *Nature* **2018**, *556*, 231–234. [CrossRef] [PubMed]
6. Proctor, M.C.; Oliver, M.J.; Wood, A.J.; Alpert, P.; Stark, L.R.; Cleavitt, N.L.; Mishler, B.D. Desiccation tolerance in bryophytes: A review. *Bryol.* **2007**, *110*, 595–621. [CrossRef]

7. Vitt, D.H.; Crandall-Stotler, B.; Wood, A. Bryophytes: Survival in a dry world through tolerance and avoidance. Plant ecology and evolution in harsh environments. In *Plant Ecology and Evolution in Harsh Environments*; Rajakaruna, N., Boyd, R., Harris, T., Eds.; Nova Publishers: New York, NY, USA, 2014; pp. 267–295.
8. Heikkinen, R.K.; Luoto, M.; Araújo, M.B.; Virkkala, R.; Thuiller, W.; Sykes, M.T. Methods and uncertainties in bioclimatic envelope modelling under climate change. *Prog. Phys. Geogr.* **2006**, *30*, 751–777. [CrossRef]
9. Iverson, L.R.; Prasad, A.M.; Matthews, S.N.; Peters, M.P. Lessons learned while integrating habitat, dispersal, disturbance, and life history traits into species habitat models under climate change. *Ecosystems* **2011**, *14*, 1005–1020. [CrossRef]
10. Plášek, V.; Číhal, L.; Müller, F.; Smoczyk, M.; Marková, I.; Fialová, L. Quo Vadis, *Orthotrichum pulchellum*? A Journey of Epiphytic Moss across the European Continent. *Plants* **2022**, *11*, 2669. [CrossRef] [PubMed]
11. Sofaer, H.R.; Jarnevich, C.S.; Pearse, I.S.; Smyth, R.L.; Auer, S.; Cook, G.L.; Edwards, T.C.; Guala, G.F.; Howard, T.G.; Morisette, J.T.; et al. Development and delivery of species distribution models to inform decision-making. *BioScience* **2019**, *69*, 544–557. [CrossRef]
12. Fajardo, J.; Lessmann, J.; Bonaccorso, E.; Devenish, C.; Munoz, J. Combined use of systematic conservation planning, species distribution modelling, and connectivity analysis reveals severe conservation gaps in a megadiverse country (Peru). *PLoS ONE* **2014**, *9*, e114367. [CrossRef] [PubMed]
13. Miranda, E.B.; Menezes, J.F.S.; Farias, C.C.; Munn, C.; Peres, C.A. Species distribution modeling reveals strongholds and potential reintroduction areas for the world's largest eagle. *PLoS ONE* **2019**, *14*, e0216323. [CrossRef] [PubMed]
14. Deneu, B.; Servajean, M.; Botella, C.; Joly, A. Evaluation of deep species distribution models using environment and cooccurrences. In *Experimental IR Meets Multilinguality, Multimodality, and Interaction, Proceedings of the 10th International Conference of the CLEF Association, CLEF 2019, Lugano, Switzerland, 9–12 September 2019*; Springer International Publishing: New York, NY, USA, 2019; pp. 213–225.
15. Elith, J.; Graham, C.H.; Anderson, R.P.; Dudík, M.; Ferrier, S.; Guisan, A.; Hijmans, R.J.; Huettmann, F.; Leathwick, J.R.; Lehmann, A.; et al. Novel methods improve prediction of species' distributions from occurrence data. *Ecography* **2006**, *29*, 129–151. [CrossRef]
16. Blair, M.E.; Le, M.D.; Xu, M. Species distribution modeling to inform transboundary species conservation and management under climate change: Promise and pitfalls. *Front. Biogeogr.* **2022**, *14*, e54662. [CrossRef]
17. Erauskin-Extramiana, M.; Arrizabalaga, H.; Cabre, A.; Coelho, R.; Rosa, D.; Ibaibarriaga, L.; Chust, G. Are shifts in species distribution triggered by climate change? A swordfish case study. *Deep. Sea Res. Part II Trop. Stud. Oceanogr.* **2020**, *175*, 104666. [CrossRef]
18. Hughes, L. Climate change impacts on species interactions: Assessing the threat of cascading extinctions. In *Saving a Million Species: Extinction Risk from Climate Change*; Island Press/Center for Resource Economics: Washington, DC, USA, 2012; pp. 337–359.
19. Zhu, Y.; Wei, W.; Li, H.; Wang, B.; Yang, X.; Liu, Y. Modelling the potential distribution and shifts of three varieties of Stipa tianschanica in the eastern Eurasian Steppe under multiple climate change scenarios. *Glob. Ecol. Conserv.* **2018**, *16*, e00501. [CrossRef]
20. Zhang, Y.; Clauzel, C.; Li, J.; Xue, Y.; Zhang, Y.; Wu, G.; Giraudoux, P.; Li, L.; Li, D. Identifying refugia and corridors under climate change conditions for the Sichuan snub-nosed monkey (*Rhinopithecus roxellana*) in Hubei Province, China. *Ecol. Evol.* **2019**, *9*, 1680–1690. [CrossRef] [PubMed]