Colegio de Postgraduados

The multidimensionality of Ecophysiology in forests

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ABSTRACT

Objective: This study describes the multidimensionality and significance of ecophysiology in forests within the context of climate change.

Design/methodology/approach: A comprehensive review and classification of scientific articles indexed in the Google and Google Scholar repository was conducted. The focus was on articles related to the importance, functions, and history of ecophysiology, as well as its relationship with forests.

Results: Ecophysiological studies are fundamental for understanding how plants have evolved in response to environmental changes through centuries. Research in this discipline has increased significantly over the last decade, particularly concerning aspects of climate change.

Limitations on study/implications: This review relied exclusively on publications available in Google and Google Scholar.

Findings/conclusions: Knowledge of forest ecophysiology is fundamental to predicting how plants undergo adaptations to future environmental changes, including the effects of climate change.

Keywords: ecophysiology, adaptation, organisms, climate.

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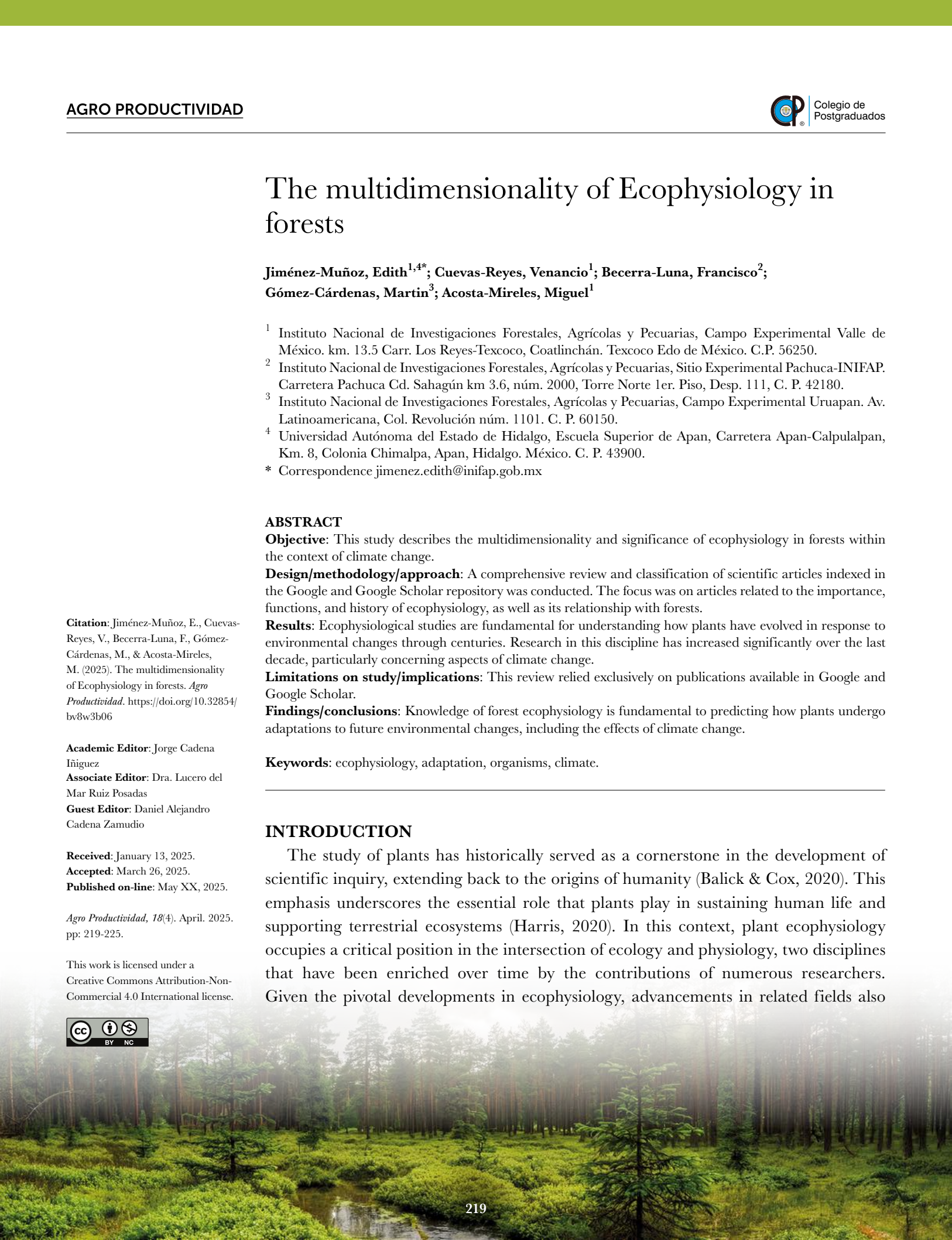
INTRODUCTION

The study of plants has historically served as a cornerstone in the development of scientific inquiry, extending back to the origins of humanity (Balick & Cox, 2020). This emphasis underscores the essential role that plants play in sustaining human life and supporting terrestrial ecosystems (Harris, 2020). In this context, plant ecophysiology occupies a critical position in the intersection of ecology and physiology, two disciplines that have been enriched over time by the contributions of numerous researchers. Given the pivotal developments in ecophysiology, advancements in related fields also



directly benefit this discipline by providing a comprehensive conceptual framework to understand the complex interactions between plants and their environment (Cavieres *et al.*, 2016; Wilkening *et al.*, 2024). By integrating principles from both ecology and physiology, ecophysiology plays a crucial role in studying and understanding how environmental factors influence the physiological processes of plants and how they adapt to their surroundings (Ainsworth *et al.*, 2016). Plant ecophysiology and ecology are interconnected fields that focus on different aspects of plant life and their interactions with the environment (Ainsworth *et al.*, 2016). Ecophysiology specifically investigates how the physiological processes of plants respond to environmental factors such as light, water, and nutrients. It emphasizes the underlying mechanisms of these responses and their implications for plant growth and survival. By integrating knowledge from both physiology and ecology, ecophysiology provides insights into how plants adapt to varying conditions in their natural habitats (Lambers *et al.*, 2019).

In contrast, ecology is a broader discipline that studies the relationships between organisms, including plants, and their environment. It encompasses various interactions within ecosystems, such as competition, predation, and symbiosis, as well as the distribution and abundance of species. While ecology can provide context for understanding plant behavior within ecosystems (Begon & Townsend, 2020), ecophysiology explores deeper into the physiological mechanisms that underpin these ecological interactions (Ainsworth *et al.*, 2016).

Interactions among plants, soils, and soil biota have been studied for centuries, initially from agricultural or forestry perspectives but more recently from a fundamental and theoretical ecological approach. This evolution in focus highlights the multidimensionality of ecophysiology, which considers multiple factors affecting plants simultaneously, such as water, soil, light, and climatic conditions. In forests, where these interactions are particularly complex, this multidimensionality is essential for understanding how plant species adapt to their environment and respond to environmental changes.

In 1866, Ernst Haeckel coined the term "ecology" and defined it as the science that focuses on the relationships between organisms and their environment, thereby establishing a foundation for studying interactions between organisms and their environmental conditions. Building on this foundation, Pickett *et al.* (1994) suggested that ecology emerged from the need for emphasizing, by Schimper, to integrate physiology and biogeography (Lüttge & Scarano, 2004). This interdisciplinary perspective allows for a comprehensive understanding of how organisms adapt to their environments. In the context of climate change, this multidimensionality becomes even more critical.

Forests face unprecedented challenges due to rapid changes in temperature, precipitation patterns, and extreme weather events. Ecophysiology provides tools to better understand how these factors affect plants from an integrative perspective. A fundamental aspect is the inherent multidimensionality of forest ecophysiology, which considers the complex interactions among plant physiology, soil dynamics, climatic conditions, and biological interactions between species. By addressing these multiple dimensions, a more comprehensive understanding is achieved for regarding how trees interact with their environment and respond to environmental factors such as light, water, and nutrients.

Thus, the objective of this review is to describe the multidimensionality and significance of ecophysiology in forests within the context of climate change.

MATERIALS AND METHODS

The methodology employed in this review is based on a qualitative and exploratory approach designed to identify and analyze key concepts and significant advancements in the field of forest ecophysiology within the context of climate change. A comprehensive bibliographic search was conducted using keywords such as "forest ecophysiology" and "climate change" in the Google and Google Scholar database. This platform was selected for its accessibility and extensive coverage of scientific literature, facilitating the collection of relevant information across various disciplines and formats (Biblioteca Complutense, 2025).

A total of 35 references were selected, including research articles, books, and book chapters. The inclusion criteria were: i) publications addressing the ecophysiology of plants or forests; ii) studies analyzing the responses of forest ecosystems to climate change; and iii) works relevant to understanding physiological and ecological mechanisms in forest environments. The references include a broad time range from 1974 to 2024, allowing for the incorporation of both historical studies and recent advancements. Furthermore, the analyzed documents are available in both English and Spanish, ensuring a bilingual and multicultural perspective in data interpretation.

A bibliometric analysis was not conducted, as the primary objective was to synthesize key information and construct a coherent conceptual framework that allows for a profound understanding of forest ecophysiology in the context of climate change. A prior qualitative focus was carried out due to the dynamic and complex nature of the field, where interactions among biological, ecological, and environmental factors are fundamental. Additionally, bibliometric analysis can be limited by its reliance on quantitative metrics that do not always adequately reflect conceptual relevance or study quality. By concentrating on the depth and relevance of content, we aim to provide a more integrated perspective that can guide future research in this area.

RESULTS AND DISCUSSION

Plant ecophysiology, its origins

Ernst Stahl (1848-1919) is acknowledged as a foundational figure in ecophysiology, having introduced experimental techniques that significantly advanced plant physiology by exploring the functions of stomata in transpiration and photosynthesis, thus establishing key principles for understanding plant-environment interactions (Lüttge, 2007; Lüttge & Scarano, 2004). In the 20th century, researchers like Otto Stocker and Bruno Huber expanded upon Stahl's work by creating innovative instruments that allowed for precise measurements of plant behavior in natural settings, focusing on essential physiological processes (Valladares & Rodríguez-López, 2010). The technological advancements of the 1970s and 1980s further propelled the field, enabling *in situ* assessments of critical environmental variables. A significant study by Kathleen Green and Robert Wright (1977) illustrated that increased atmospheric CO_2 levels could linearly enhance the net

photosynthesis of *Pinus ponderosa* (Green & Wright, 1977). Subsequent investigations revealed that water stress markedly limits gas exchange and photosynthetic efficiency in *Pinus radiata*, underscoring the vital role of water availability for forest productivity and the necessity for effective water management strategies (Benecke, 1980). As the 21st century outspread, ecophysiology regained prominence in high-impact scientific literature, integrating mechanisms at the individual level to analyze ecological and evolutionary phenomena (Valladares & Rodríguez-López, 2010). Collectively, the contributions of early ecophysiologists like Stahl have been instrumental in enhancing our comprehension of how plants adapt to ever-changing environmental conditions.

Gilbert Aussenac (2000) explored the influence of forest stands on microclimatic conditions and their implications for plant ecophysiology, emphasizing the role of local climatic characteristics in shaping microclimates that affect temperature, light, and water availability. This understanding is vital for optimizing silvicultural practices to enhance forest health and productivity. Additionally, research indicates that conifers in the Sierra Nevada ecotone utilize soil moisture more efficiently than shrubs, underscoring the importance of water availability for their survival in montane environments (Royce & Barbour, 2001). Recent advancements, such as using thermal cameras to monitor tree transpiration, further highlight the necessity of effective water management and ecophysiological knowledge for sustaining forest ecosystems amid climate change (Javadian *et al.*, 2024).

In 2024, Joshi *et al.* examined seasonal variations in the ecophysiological traits of leaves from coexisting perennial and deciduous tree species in a white oak forest (*Quercus leucotrichophora*) in the central Himalayas, focusing on traits such as net photosynthetic capacity and stomatal conductance. Their findings highlighted distinct strategies employed by these trees in response to seasonal changes, which are essential for their growth and survival. This research contributes to our understanding of species coexistence and their ecological roles in temperate forest ecosystems, providing insights for forest management programs and conservation efforts in the Himalayan region (Joshi *et al.*, 2024). Furthermore, it emphasizes the necessity for long-term physiological monitoring to address climate change impacts on forest health and productivity, as current funding often prioritizes innovative but less effective projects over critical in situ studies (Ruhil *et al.*, 2024). Recent studies have indicated that the vulnerability of species such as *Liquidambar styraciflua* is linked to factors like stomatal conductance and leaf water potential, with water being a key determinant for their development. These investigations not only aid at assessing species resilience to climate change but are also vital for developing management and conservation strategies that benefit both ecosystems and local communities (Esperón-Rodríguez & Barradas, 2015).

Approaches to ecophysiology in forest ecosystems

Plant ecophysiology is a crucial discipline that investigates the physiological mechanisms behind ecological interactions, focusing on how plants acclimate, adapt, and grow in response to environmental factors. By examining these processes at molecular, biochemical, and physiological levels, ecophysiology bridges botany, plant physiology, and

ecology, enhancing our understanding of plant responses to critical factors such as water availability, light, and nutrients (Huante *et al.*, 2002; Lambers *et al.*, 2019).

This field plays a vital role in addressing climate change and resource scarcity by providing insights into how physiological processes influence plant adaptation to changing conditions (Ainsworth *et al.*, 2016; Hasanuzzaman, 2020a, 2020b). Through the analysis of plants at both molecular and whole-plant levels, researchers gain valuable knowledge about species thriving in diverse environments and their responses to environmental stressors (Bhatla & Lal, 2023; Felisberto *et al.*, 2024; Mendes *et al.*, 2023). This understanding is essential for managing community dynamics and ecosystem functioning in the face of environmental changes (Halofsky *et al.*, 2020; Wallis *et al.*, 2021).

Ecophysiological studies provide a foundation for understanding processes from tissues to ecosystems (Ainsworth *et al.*, 2016). By exploring the relationships between physiological traits and environmental conditions, researchers can assess ecosystem efficiency and resilience to fluctuations in climate and resources. This knowledge elucidates how specific traits enable survival and competition among species, influencing their distribution and trait expression along ecological gradients (Buzhdygan *et al.*, 2020; Medina, 1977; Smith *et al.*, 2023; Maciel-Mata *et al.*, 2015; Visakorpi *et al.*, 2023).

Current importance of plant ecophysiology

Plant ecophysiology deepens our understanding of plant evolution, productivity, and nutrient use efficiency by examining their adaptation to ecosystems over time. This knowledge is essential for developing strategies to harness plants and forests in mitigating global climate change. In particular, the ecophysiological analysis of forests provides a detailed link between tree phenology, physiology, and climatic influences, offering critical insights into the complex interactions and feedback mechanisms that shape tree-environment dynamics in the face of the ongoing climate crisis (Stagakis *et al.*, 2022).

Plant productivity is closely linked to their ability to efficiently utilize available soil nutrients. Ecophysiology investigates the mechanisms that enable plants to absorb and utilize essential nutrients, including nitrogen, phosphorus, and potassium, which are critical for growth in natural environments. This study also considers the interactions among all biotic and abiotic factors within ecosystems (Ainsworth *et al.*, 2016; Becklin *et al.*, 2016; Reichardt *et al.*, 2020).

CONCLUSIONS

Through time, plant ecophysiology has established itself as a fundamental discipline focused on understanding the physiological processes that regulate plant responses to environmental factors. This field not only contributes to our understanding of plant evolution but also enables the interpretation of their productivity past, present, and future as well as their nutrient use efficiency. Additionally, plant ecophysiology provides new insights into the adaptation of plants to specific ecosystems. By analyzing these interactions throughout different temporal scales, it becomes possible to develop strategies for the sustainable management of plants and forests. This may be crucial for maintaining

vegetation cover with carbon repositories and contributing to the mitigation of global climate change.

REFERENCES

Ainsworth, E. A., Bernacchi, C. J., & Dohleman, F. G. (2016). Focus on ecophysiology. *Plant physiology, 172*(2), 619-621

Aussenac, G. (2000). Interactions between forest stands and microclimate: ecophysiological aspects and consequences for silviculture. *Annals of forest science, 57*(3), 287-301. DOI: 10.1051/forest:2000119

Balick, M. J., & Cox, P. A. (2020). Plants, people, and culture: the science of ethnobotany. Garland Science

Becklin, K. M., Anderson, J. T., Gerhart, L. M., Wadgymar, S. M., Wessinger, C. A., & Ward, J. K. (2016). Examining plant physiological responses to climate change through an evolutionary lens. *Plant physiology, 172*(2), 635-649. https://doi.org/10.1104/pp.16.00793

Begon, M., & Townsend, C. R. (2020). Ecology: from individuals to ecosystems. John Wiley & Sons.

Benecke, U. (1980). Photosynthesis and transpiration of *Pinus radiata* D. Don under natural conditions in a forest stand. *Oecologia*, 44, 192-198. https://doi.org/10.1007/BF00572679

Bhatla, S. C., & Lal, M. A. (2023). Plant physiology, development and metabolism. Springer Nature.

Biblioteca Complutense. (2025). Google Académico: guía básica . Universidad Complutense de Madrid. Recuperado el 23 de enero de 2025 de https://biblioguias.ucm.es/google-academico

Buzhdygan, O. Y., Meyer, S. T., Weisser, W. W., Eisenhauer, N., Ebeling, A., Borrett, S. R., ... & Petermann, J. S. (2020). Biodiversity increases multitrophic energy use efficiency, flow and storage in grasslands. *Nature Ecology & Evolution, 4*(3), 393-405. https://doi.org/10.1038/s41559-020-1123-8

Cavieres, L. A., Sáez, P., Sanhueza, C., Sierra-Almeida, A., Rabert, C., Corcuera, L. J., ... & Bravo, L. A. (2016). Ecophysiological traits of Antarctic vascular plants: their importance in the responses to climate change. *Plant Ecology*, 217, 343-358. https://doi.org/10.1007/s11258-016-0585-x

Esperón-Rodríguez, M., & Barradas, V. L. (2015). Comparing environmental vulnerability in the montane cloud forest of eastern Mexico: A vulnerability index. *Ecological Indicators*, 52, 300-310. https://doi.org/10.1016/j.ecolind.2014.12.019

Felisberto, J. S., Machado, D. B., Assunção, J. A., Massau, S. A., Queiroz, G. A. D., Guimarães, E. F., ... & Moreira, D. D. L. (2024). Spatio-Temporal Variations of Volatile Metabolites as an Eco-Physiological Response of a Native Species in the Tropical Forest. *Plants, 13*(18), 2599.

Green, K., & Wright, R. (1977). Field Response of Photosynthesis to CO_2 Enhancement in Ponderosa Pine. *Ecology, 58*(3), 687-692. https://doi.org/10.2307/1939020

Halofsky, J. E., Peterson, D. L., & Harvey, B. J. (2020). Changing wildfire, changing forests: the effects of climate change on fire regimes and vegetation in the Pacific Northwest, USA. *Fire Ecology, 16*(1), 1-26. https://doi.org/10.1186/s42408-019-0062-8

Harris, D. R. (2020). An evolutionary continuum of people–plant interaction. In The Emergence of Agriculture (pp. 26-44). Routledge

Hasanuzzaman, M. (Ed.). (2020a). Plant ecophysiology and adaptation under climate change: mechanisms and perspectives I: general consequences and plant responses. Springer Nature.

Hasanuzzaman, M. (Ed.). (2020b). Plant Ecophysiology and Adaptation under Climate Change: Mechanisms and Perspectives II: Mechanisms of Adaptation and Stress Amelioration. Springer Nature.

Huante, P., Barradas, V. L., & Rincón, E. (2002). Ecofisiología vegetal. Historia Natural de Chamela, Universidad Nacional Autónoma de México, 473-489.

Javadian, M., Aubrecht, D. M., Fisher, J. B., Scott, R. L., Burns, S. P., Diehl, J. L., ... & Richardson, A. D. (2024). Scaling individual tree transpiration with thermal cameras reveals interspecies differences to drought vulnerability. *Geophysical Research Letters, 51*(20), e2024GL111479. https://doi.org/10.1029/2024GL111479

Joshi, R. K., Gupta, R., Mishra, A., & Garkoti, S. C. (2024). Seasonal variations of leaf ecophysiological traits and strategies of co-occurring evergreen and deciduous trees in white oak forest in the central Himalaya. *Environmental Monitoring and Assessment, 196*(7), 634. https://doi.org/10.1007/s10661-024-12771-3

Lambers, H., Oliveira, R. S., Lambers, H., & Oliveira, R. S. (2019). Introduction: history, assumptions, and approaches. *Plant physiological ecology*, 1-10. https://doi.org/10.1007/978-3-030-29639-1_1

Lüttge, U. (2007). Physiological ecology of tropical plants. Springer Science & Business Media.

Lüttge, U., & Scarano, F. R. (2004). Ecophysiology. *Brazilian Journal of Botany*, 27, 1-10.

Maciel-Mata, C. A., Manríquez-Morán, N., Octavio-Aguilar, P., & Sánchez-Rojas, G. (2015). El área de distribución de las especies: revisión del concepto. *Acta universitaria, 25*(2), 03-19. https://doi.org/10.15174/au.2015.690

Medina, E. (1977). Introducción a la ecofisiología vegetal. Programa Regional de Desarrollo Científico y Tecnológico, Departamento de Asuntos Científicos, Secretaría General de la Organización de los Estados Americanos.

Mendes, G. C., Müller, C., & Almeida, A. M. (2023). Physiological, biochemical and molecular approaches in response to abiotic stresses in plants. *Frontiers in Plant Science*, 14, 1194937. doi: 10.3389/fpls.2023.194937

Reichardt, K., Timm, L.C. (2020). How Plants Absorb Nutrients from the Soil. In: Soil, Plant and Atmosphere. Springer, Cham. https://doi.org/10.1007/978-3-030-19322-5_16

Royce, E. B., & Barbour, M. G. (2001). Mediterranean climate effects. I. Conifer water use across a Sierra Nevada ecotone. *American Journal of Botany, 88*(5), 911-918. https://doi.org/10.2307/2657044

Ruhil, T., Singh, H., & Barthwal, S. (2024). Long-Term Physiological Monitoring for Detecting Climate Change Impacts on Forest Ecosystems. In H. Singh (Ed.), Forests and Climate Change: Biological Perspectives on Impact, Adaptation, and Mitigation Strategies (pp. 817-834). Springer Nature Singapore. https://doi.org/10.1007/978-981-97-3905-9_39

Smith, D. D., Adams, M. A., Salvi, A. M., Krieg, C. P., Ané, C., McCulloh, K. A., & Givnish, T. J. (2023). Ecophysiological adaptations shape distributions of closely related trees along a climatic moisture gradient. *Nature Communications, 14*(1), 7173. https://doi.org/10.1038/s41467-023-42352-w

Stagakis, S., Markos, N., Vanikiotis, T., Levizou, E., & Kyparissis, A. (2022). Multi-Year Monitoring of Deciduous Forests Ecophysiology and the Role of Temperature and Precipitation as Controlling Factors. *Plants, 11*(17), 2257. https://doi.org/10.3390/plants11172257

Valladares, F., & Rodríguez-López, N. F. (2010). Ecofisiología, una aproximación mecanicista a los procesos ecológicos. *Ecosistemas, 19*(1).

Visakorpi, K., Block, S., Pellissier, L., Levine, J. M., & Alexander, J. (2023). Eco-physiological and morphological traits explain alpine plant species' response to warming. *Functional Ecology, 37*(2), 287-301. https://doi.org/10.3929/ethz-b-000587865

Wallis, C. I., Tiede, Y. C., Beck, E., Böhning-Gaese, K., Brandl, R., Donoso, D. A., ... & Bendix, J. (2021). Biodiversity and ecosystem functions depend on environmental conditions and resources rather than the geodiversity of a tropical biodiversity hotspot. *Scientific Reports, 11*(1), 24530. https://doi.org/10.1038/s41598-021-03488-1

Wilkening, J. V., Feng, X., Dawson, T. E., & Thompson, S. E. (2024). Different roads, same destination: The shared future of plant ecophysiology and ecohydrology. *Plant, Cell & Environment, 47*(9), 3447-3465.