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Comment

University forests and carbon sequestration: an untapped potential

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Abstract
The role of universities in addressing climate change is often discussed, but one crucial aspect tends to be overlooked: their potential contribution to carbon sequestration. Many universities around the world possess significant tracts of land, often featuring substantial forested areas. These landscapes represent an underutilised opportunity for nature-based solutions that facilitate carbon sequestration. This paper discusses the current trends and status of university-owned forests, highlighting some of the largest and most ecologically significant forests managed by academic institutions across different regions worldwide. It explores their capacity for carbon sequestration, their biodiversity value, and the potential they hold for contributing to global climate change mitigation efforts. Furthermore, the article examines how these university forests can serve as dynamic, living laboratories for research, education, and conservation, as well as spaces for community engagement. In addition to their environmental benefits, these green spaces can enhance human health and well-being. Based on this analysis, the paper offers recommendations for universities on how to optimise their forested lands as carbon sinks and enhance their role in advancing sustainable practices, research, and education.

Article Highlights

- Presents an agenda-setting synthesis on measures universities can deploy to enhance their forested landscapes as carbon sinks and in situ living labs for research and education.
- Illustrates the manifold benefits of university forests through twelve case studies spanning five continents.
- Demonstrates how university forests may be harnessed for conservation, health, and well-being.
- Spotlights an under-recognised area in higher education, presenting opportunities for universities that may inspire similar initiatives beyond the featured cases.

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1 Introduction

The global climate crisis has spurred an urgent need for effective carbon sequestration strategies. Forests, as natural carbon sinks, play a crucial role in mitigating climate change [1]. Universities, as significant landowners, have the potential to contribute meaningfully to these efforts through sustainable forest management practices. In recent years, university forests have gained increasing attention for their capacity to enhance carbon sequestration—the process by which carbon dioxide (CO_2) is stored by trees and other vegetation—thereby mitigating the effects of climate change [2] while at the same time supporting biodiversity conservation [3] and sustainable management practices [4]. As climate change intensifies, there is a growing need to understand how forests can contribute to reducing atmospheric carbon levels through effective management practices [5]. In this paper, university forests are defined as designated areas of forestland that are owned, managed, or utilised by a university or academic institution for purposes such as research, education, conservation, and resource management [6]. These forests often serve as living laboratories where students, faculty, and researchers can engage in field-based studies, explore sustainable forest management practices, and conduct experiments related to forestry, ecology, biodiversity, and environmental science, as well as recreation. They play a critical role in research, education, conservation, and sustainable resource management.

Universities can contribute to carbon sequestration through their forested landscapes by focusing on three broad and interconnected areas.

The *first* major benefit of university forests is their *capacity for carbon storage*. Acting as significant carbon sinks, these forests absorb atmospheric CO_2 through the process of photosynthesis, playing a crucial role in mitigating climate change [6]. Trees capture and store carbon within their biomass, including trunks, branches, leaves, and even roots, which helps reduce the amount of carbon dioxide in the atmosphere [7]. This carbon storage process is not only limited to the living biomass; it also extends to the soil, where carbon is stored as organic matter over time, contributing to the overall carbon sequestration potential of these ecosystems. University forests are often composed of a wide range of tree species, including both mature and young trees, which enhances their ability to capture and store carbon efficiently. The diversity and age variation in these forests mean that they can sequester substantial amounts of carbon over prolonged periods, making them effective in contributing to long-term carbon sequestration strategies. This is particularly important as diverse forest ecosystems have been shown to be more resilient and capable of storing more carbon compared to monoculture plantations. In addition to direct carbon capture, some universities have engaged in carbon offset programs, which involve calculating the institution's overall carbon emissions and then investing in projects that can sequester or offset an equivalent amount of carbon elsewhere [8]. These initiatives often include reforestation, afforestation, or improved forest management practices, which help in enhancing the carbon absorption capacity of university lands. By leveraging their forested areas as a natural asset for carbon sequestration, universities can play a proactive role in offsetting their own emissions and achieving net-zero or net-negative goals. Furthermore, university forests offer opportunities to participate in carbon credit trading markets, where the sequestered carbon can be quantified, verified, and sold as carbon credits. This creates an additional revenue stream for universities and also offers them an incentive to maintain and expand their forested areas, thus reinforcing their role in climate action efforts [9]. By serving as long-term carbon sinks, these forests support universities in meeting their sustainability targets and contribute to broader efforts in mitigating global climate change.

The *second* area of focus is intrinsically linked to *biodiversity and the provision of a wide range of ecosystem services*. University forests often encompass a wide variety of ecosystems, which support an extensive array of plant and animal species, contributing to regional and global biodiversity [3]. This biodiversity is not just a measure of ecological richness but also plays a fundamental role in maintaining the health and stability of ecosystems. A diverse range of species ensures that forest ecosystems are more resilient to environmental stresses, such as pests, diseases, and the impacts of climate change, thereby sustaining the forests' ability to adapt to changing conditions. This resilience is critical for the long-term viability of forests as effective carbon sinks [6, 10]. Moreover, university forests established through afforestation and reforestation efforts offer significant opportunities to enhance ecosystem services. Afforestation involves planting trees in areas that have historically lacked forest cover, while reforestation involves restoring tree cover in areas that were previously deforested or converted to other land uses. Both practices are vital for expanding forest cover and, consequently, the carbon sequestration potential of university lands. By focusing on these activities, universities can play an active role in mitigating climate change and reversing biodiversity loss. Afforestation and reforestation projects often prioritise the planting of fast-growing tree species with a high

potential for carbon storage, which can rapidly increase the overall carbon sequestration capacity of these lands [11]. However, the selection of tree species should also consider the promotion of native biodiversity, ensuring that these efforts support not only carbon capture but also the conservation of local wildlife, soil health, water regulation, and other ecosystem services. Furthermore, university forests can serve as invaluable natural study environments where students, researchers, and local communities can engage in hands-on learning, research, and conservation activities, deepening their understanding of sustainable forest management practices and the intricate relationships between biodiversity and climate change. In this way, university forests are positioned to become living models of how biodiversity conservation and climate action can be synergistically achieved.

The *third* area of significance lies in the unique potential of university forests to function as *dynamic living laboratories for research, education, and community engagement*. These forested landscapes offer unparalleled opportunities for scientists, researchers, and students to delve deeply into the complexities of forest ecosystems, providing first-hand experience in studying the mechanisms, processes, and timescales involved in carbon sequestration [6]. This practical exposure allows for the investigation of how different factors, such as species composition, soil health, and climate variables, influence carbon storage. In their role as living laboratories, university forests provide an invaluable space for testing and experimenting with various silvicultural practices, including tree thinning, selective harvesting, reforestation techniques, and sustainable forest management strategies. By examining these practices over time, researchers can generate data that contribute to optimising carbon sequestration potential, thereby enhancing our understanding of how forests can be managed to maximise their role as carbon sinks [4]. Beyond research, these forests serve as vital educational resources and outreach centres that may actively engage not only students and faculty but also the surrounding community. As such, university forests become outdoor classrooms where learners from diverse backgrounds can gain insights into the importance of different tree species in supporting carbon sequestration, biodiversity conservation, and overall climate change mitigation. By facilitating experiential learning, university forests help nurture a deeper understanding of ecological principles, the value of sustainable resource management, and the interconnections between human actions and environmental outcomes [5]. Furthermore, by acting as hubs for environmental education and awareness, university forests have the potential to inspire broader societal engagement in conservation efforts. The knowledge and skills gained from embodied experiences can foster a culture of sustainability among future leaders, encouraging the adoption of sustainable practices beyond conventional university study spaces [12]. This ripple effect can extend into local communities, regional policy-making, and even global environmental initiatives, promoting sustainable forest management practices, biodiversity protection, and climate resilience across broader landscapes and worldviews. As such, university forests not only contribute to advancing scientific understanding but also play a crucial role in shaping a more sustainable and climate-conscious society.

It is important to recognise that the specific contribution of university forests to carbon sequestration can be highly variable, influenced by a range of factors such as forest size and age, tree species composition, management practices, soil type, climate conditions, and geographical location [13, 14]. For instance, older forests with mature trees typically sequester more carbon overall, but younger, rapidly growing forests can have a higher rate of carbon uptake. The diversity and species composition of trees also play a significant role, as certain species are more efficient at carbon absorption than others. Additionally, the way these forests are managed—whether through practices such as selective logging, controlled burning, or reforestation—can substantially affect their carbon storage capacity over time. Despite this inherent variability, university forests have the unique potential to serve as hubs of innovation by promoting research, education, and sustainable forest management. They can provide invaluable data on how different forest ecosystems respond to changing climate conditions, forest management strategies, and conservation interventions [6]. This knowledge can be used to inform best practices for enhancing carbon sequestration in forests on a wider scale. Moreover, by acting as living laboratories, university forests can inspire students, researchers, and the public to engage with conservation efforts and develop solutions that could be applied to larger landscapes. In this way, university-managed forests have the potential not only to make a significant contribution to carbon sequestration but also to play a crucial role in advancing knowledge in areas of forest ecosystems, fostering sustainable management practices, and inspiring broader societal efforts toward conservation and climate action [9].

Even so, despite these clear benefits linked to university forests, there remains a need for more comprehensive research to understand how they may be optimised for multiple objectives, including education, carbon sequestration, and biodiversity conservation. The optimal strategies for maximising carbon sequestration while ensuring the long-term health and resilience of university forests remain a subject of ongoing debate. While there is a body of research highlighting the general benefits of university forests, there is a gap in the literature regarding how different institutions implement and manage these spaces to maximise and reap their ecological and educational impact. This study aims to address this

gap by providing a comparative analysis of how different universities worldwide manage their forests, examining the strategies and measures employed to balance ecological, educational, and economic goals, and seeking to contribute to a deeper understanding of best practices in university forest management and carbon sequestration.

2 Distribution of university forests

The distribution of university forests around the world can vary significantly depending on the country, region, and individual universities' priorities and resources. It is important to note that the specific designation of university forests can vary. Some universities may have designated forest areas within their campuses, while others may own larger forested properties located further away. Additionally, some universities may collaborate with external organisations or share resources with other academic institutions in managing forests. While the provision of an exhaustive list of all university forests globally is not practical, this paper highlights some notable examples from different regions. A set of four criteria were used for selecting 'notable' forest locations for university-led conservation schemes. The first is their role as biodiversity hotspots. The selected forests are home to a wide range of species, including rare, endangered, or endemic species that require active conservation efforts. The second criterion is their research potential since the locations offer the potential for long-term ecological and environmental research, particularly in the areas of climate change, forest dynamics, and species adaptation. They all have a history of scientific research and continued academic study. The third criterion relates to conservation needs. The selected forests are all suitable for university-led conservation to protect vulnerable ecosystems. Finally, the proximity to universities was considered. The study included forests that are accessible to students, faculty, and researchers, and where conservation efforts aimed at restoring habitat connectivity to enhance species mobility and ecosystem resilience could be readily observed. Based on these criteria, the study included the following university forests.

2.1 North America

- Harvard Forest (Massachusetts, USA): Managed by Harvard University, it is one of the oldest and most renowned university forests in the United States [15].
- Yale Myers Forest (Connecticut, USA): Operated by Yale University, this forest is used for research, education, and recreation purposes [16].
- University of British Columbia Malcolm Knapp Research Forest (British Columbia, Canada): A teaching and research forest managed by the University of British Columbia [17].

2.2 Europe

- Oxford University Forest (England, UK): Located in Wytham, near Oxford, this forest is owned and managed by the University of Oxford [18]. It serves as a living laboratory for ecological research.
- Wageningen University Forest (Gelderland, Netherlands): Managed by Wageningen University, it provides an outdoor classroom for students and accommodates various scientific studies [19].
- University of Freiburg Forest (Baden-Württemberg, Germany): Situated near Freiburg, this forest belongs to the University of Freiburg and is used for research and educational purposes [20, 21].

2.3 Asia–Pacific

- Kyoto University Forest (Kyoto, Japan): Operated by Kyoto University, it serves as a research site for ecological and environmental studies [22].
- National University of Singapore Kent Ridge Forest (Singapore): Located within the campus, this forest is used for research, teaching, and community engagement [23].
- University of Melbourne Dookie Campus (Victoria, Australia): This campus includes agricultural research stations and farmland used for teaching and research [24].

Fig. 1 Global sample of selected university forests (not to scale)

2.4 South America

- University of São Paulo Forest (São Paulo, Brazil): Known as 'Cidade Universitária Armando de Salles Oliveira', this forest is part of the University of São Paulo's campus and serves as an ecological reserve for research and conservation [25].
- Universidad Austral de Chile Valdivia Experimental Forest (Valdivia, Chile): Managed by the Universidad Austral de Chile, this forest is utilised for teaching, research, and sustainable forest management practices [26, 27].
- Universidad Regional Amazónica Ikiam (Tena, Ecuador) is a public university founded in 2013 and located in the Ecuadorian Amazon. Ikiam was purposely designed and built into the Amazon by government decree [28] and may be classified as having a natural 'university forest'.[1] Notably, the name *Ikiam* derives from the indigenous *shuar* language and means 'forest', thus underpinning the university's inceptive commitment to forest-linked research, conservation, and environmental sustainability [29].

Figure 1 provides a schematic map showing the position of the sampled university forests.

While the geographic scope of the listed university forests spans multiple continents, a more detailed comparison highlights variations in management practices and the influence of geographic diversity on their carbon sequestration potential. North American forests, like Harvard [15] and Yale Myers [16], often emphasise long-term ecological research and educational functions, while forests in Europe, such as Oxford [18] and Wageningen [19], are similarly research-driven but reflect regional priorities like conservation and biodiversity. In Asia–Pacific, forests like Kyoto University Forest [22] focus on ecological and environmental studies, contrasting with the more urban and community-integrated approach seen at Kent Ridge Forest in Singapore [23]. Meanwhile, South American forests, such as those managed by Universidad Austral de Chile [26, 27] and Ikiam [28, 29], integrate sustainability and indigenous knowledge into their management practices. Geographic diversity further influences carbon sequestration, as tropical forests (e.g., Ikiam) have higher

[1] The inception of Ikiam University [29] can be traced back to a consultative process in Tena, Ecuador (2013, Dec. 1–7) that invited the views of 60 academic delegates from around the world who reviewed the original *Ikiam Universidad Regional Amazónica: Proposal for the Establishment of the Amazonian University Ikiam in Ecuador* [28] in the heart of the Amazon. This paper's second author was among the invited delegates.

sequestration capacities compared to temperate forests, which underscores the importance of both local ecological conditions and forest management in determining their role as carbon assets. The examples provided above are just a snapshot of the many university forests found worldwide, as numerous other university-affiliated forests play pivotal roles in advancing research, education, and environmental conservation efforts. These forests are vital ecosystems that serve as living laboratories, offering unique opportunities for scientific studies on topics ranging from biodiversity and forest management to climate change mitigation. In addition to their academic and research functions, they often inspire public outreach, foster community involvement, and support sustainable practices, making them integral to both local and global environmental stewardship initiatives. Together, these university forests form a crucial educational network that contributes to the understanding and preservation of natural ecosystems across the globe.

3 Recommendations

To enhance the global impact of university-affiliated forests, several recommendations can be drawn from the analysis of their geographic and management diversity. Universities should leverage the distinct ecological characteristics of their forests to tailor management practices that optimise carbon sequestration. For instance, universities with tropical forests, with their higher sequestration potential, should prioritise conservation and restoration, while universities with temperate forests might focus more on sustainable management and biodiversity research. Additionally, fostering collaboration between universities across different regions—such as North America's long-term ecological research, Europe's focus on conservation, Asia–Pacific's emphasis on urban integration, and South America's use of indigenous knowledge—could lead to more comprehensive approaches to forest management. Moreover, enhancing community engagement and public outreach is essential for increasing the societal relevance of university forests. This could involve expanding educational programs and integrating sustainable practices that align with regional priorities, further supporting local conservation efforts. Finally, given the critical role university forests play in climate change research, establishing a global network for data sharing and collaborative projects could advance the understanding of ecosystem services, biodiversity, and carbon sequestration across various biomes. This integrated approach would not only enrich academic research but also reinforce the contributions of these forests to global environmental sustainability and climate change mitigation.

Focusing on Europe offers a compelling case for examining university forests due to the region's rich tapestry of ecological diversity, its strong commitment to sustainability, and its history of innovative conservation efforts that demonstrate meaningful societal and environmental impacts. European university forests serve as vital research and education hubs, addressing critical issues such as biodiversity loss, climate change, and sustainable resource management:

3.1 Hainich National Park (University of Göttingen, Germany)

The University of Göttingen has been instrumental in conservation and research within the Hainich National Park, a UNESCO World Heritage site. The park, part of one of the largest continuous deciduous forests in Europe, is a centre for ecological research on biodiversity, forest dynamics, and ecosystem services. Conservation schemes focus on protecting old-growth forests and restoring ecosystems impacted by historical land use [30].

3.2 Šumava National Park (Charles University, Czech Republic)

Charles University leads research and conservation efforts in Šumava National Park, which includes the largest forested area in the Czech Republic. Their work involves studying forest regeneration following bark beetle infestations, climate change impacts on forests, and habitat conservation for endangered species. These efforts contribute to developing new strategies for maintaining forest biodiversity and ecosystem health [31].

3.3 Cairngorms National Park (University of the Highlands and Islands, Scotland)

The University of the Highlands and Islands collaborates with Cairngorms National Park on conservation projects aimed at preserving the ancient Caledonian pine forests. Research focuses on habitat restoration, reforestation, and the reintroduction of native species like the Scottish wildcat and capercaillie. The university's efforts contribute to the park's long-term ecological sustainability through community-based forest management and biodiversity protection [32].

3.4 Montes de Valsaín (Complutense University of Madrid, Spain)

The Complutense University of Madrid plays a role in conservation and research in the Montes de Valsaín, a forest area within the Sierra de Guadarrama National Park. The university's forestry department is engaged in studies on sustainable forest management, biodiversity conservation, and the impact of climate change on Mediterranean forests. Conservation efforts here also focus on maintaining traditional silviculture while protecting the area's rich biodiversity [33].

Together, these European university-led forest conservation schemes focus on restoring ecosystems, conserving biodiversity, and developing sustainable management practices to ensure the health and resilience of forests in response to environmental challenges. Also, these and other university-led conservation schemes often integrate scientific research with hands-on fieldwork, contributing to sustainable forestry practices and the protection of forest ecosystems.

Given the positive examples of universities utilising their forests as carbon sinks, it is evident that these institutions can make a substantial contribution to mitigating climate change. By implementing effective management strategies, universities can optimise their forests' ability to absorb and store carbon dioxide. Additionally, incorporating climate change education into curricula can foster a new generation of environmentally conscious students and researchers. Furthermore, collaborative efforts between universities, governmental agencies, and non-profit organisations can facilitate knowledge sharing, resource mobilisation, and the implementation of large-scale carbon sequestration initiatives (Fig. 2).

In terms of *management*, implementing forest management practices that enhance the forest's ability to absorb carbon may include selective logging, controlled burns to reduce wildfire risk [34], and protecting old-growth forests that store large amounts of carbon. Old-growth forests provide homes to a wide variety of plant and animal species, many of which are highly dependent and can only thrive in mature ecosystems. For example, certain species, like large owls or specific fungi, depend on the structural complexity and microhabitats found only in old forests. Also, older forests contain diverse genetic resources, promoting resilience within ecosystems. This helps forests adapt to changing environmental conditions such as climate change or diseases [35]. Moreover, forested areas on university lands may be expanded through reforestation (planting trees in previously forested areas) and afforestation (creating new forests on lands that historically have not been forested). By emphasising native and diverse species that are adapted to local conditions and have high carbon sequestration capabilities, the viability and longevity of such forests may be assured [36–38]. Measures to prevent illegal logging, land conversion, and other activities threatening forest health may also be integrated as part of holistic management practices [39]. Another area associated with management is the promotion of biodiversity within university forests, as diverse ecosystems tend to be more resilient and may sequester more carbon than monocultures [38, 40, 41]. This includes maintaining a variety of tree species, undergrowth plants, and animal habitats. Relatedly, universities can also develop their own carbon offset programmes by quantifying the carbon sequestered by their forests and selling carbon credits. This not only provides a financial incentive for maintaining and expanding forested areas but also contributes to global carbon reduction efforts [42].

In respect of *education*, university forest lands may be used for research and monitoring to assess their carbon sequestration potential. This work may be performed as part of the training of students. It may involve studying different species, forest management techniques, and the impacts of climate change on forest health and carbon storage capacity. Indeed, university forests can serve as educational platforms to raise awareness about the importance of forests as carbon sinks. Academic programmes and workshops may involve students, faculty, and the local community in forest conservation and management efforts and point the way towards holistic carbon–neutral education [43].

Finally, as far as *collaboration and partnerships* are concerned, universities may collaborate with government agencies, non-profit organisations, and other institutions to share knowledge, resources, and best practices in forest management and conservation. Joint projects can leverage additional funding and expertise to enhance the carbon sequestration potential of university forests.

By implementing these measures, universities can enhance their forests' capacity to act as carbon sinks. This can be achieved through a variety of sustainable forest management practices, including:

1. *Afforestation and Reforestation:* planting new trees in previously deforested or degraded areas can significantly increase carbon sequestration, as growing forests absorb large amounts of CO_2.
2. *Sustainable Forest Management:* implementing selective logging or thinning practices that reduce damage to the ecosystem while allowing the forest to continue growing helps maintain carbon sequestration without compromising the forest's health.

Fig. 2 Schematic representation of the recommended measures universities may deploy to leverage the benefits of their forested landscapes (concept by authors)

3. *Restoring Degraded Lands:* restoring soil health through erosion control, increasing biodiversity, and managing water resources enhances the forest's ability to absorb carbon.
4. *Preventing Deforestation:* protecting forests from deforestation and human encroachment ensures that existing carbon sinks remain intact and continue to sequester carbon.

Overall, by preventing habitat destruction and limiting land conversion for agriculture or urban development, universities can maintain and enhance their forests' role in absorbing CO_2 and are able to serve as efficient, long-term carbon sinks.

Moreover, university-linked forests are incubators for biodiversity, research and innovation, thus underpinning a range of services that may encompass carbon sequestration, conservation, and potentially the discovery of new medicinal resources and pharmaceutical compounds linked to life-saving drugs, in addition to offering other trickle-down benefits that may be associated with forest-based recreation and human mental health and well-being (e.g., hiking, birdwatching, and wildlife observation, which foster a meaningful connection between people and nature) [44]. University forests can meaningfully contribute to this conservation and sustainability agenda; their contributions should be more systematically enlisted and documented and may involve the following areas (Fig. 3).

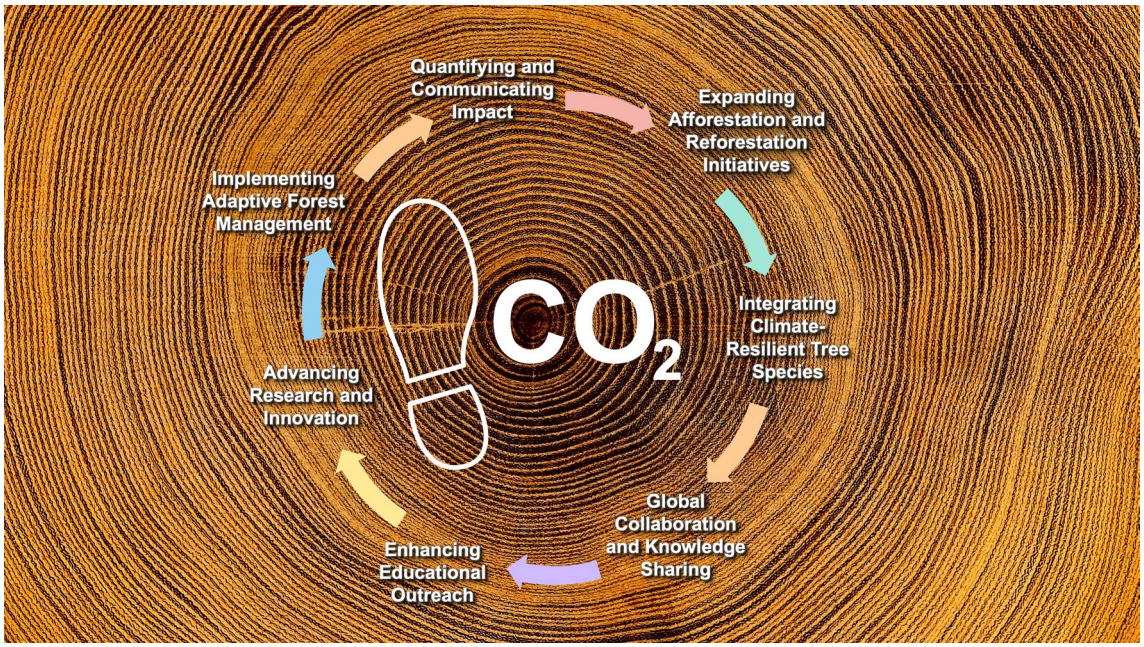

Fig. 3 Schematic representation of selected priority areas of action linked to the sustainable use of university forests (concept by authors)

These recommendations apply not only to the forests described in this paper but also to others. All around the world, there is a perceived need to preserve university forest locations to maximise their significant ecological, educational, and conservation value, enhancing both the impact of research and the preservation of vital natural resources. In order to yield the expected benefits, recommendations to conserve university forests need to be supported by strong institutional commitment and sustained leadership support. More concretely, university leadership must prioritise forest conservation as part of their institutional mission. Dedicated funding, staff, and long-term strategies are essential to ensuring the sustainability of conservation efforts. Also, universities should develop and enforce conservation policies, including sustainable forest management practices, biodiversity protection, and climate resilience plans, to guide day-to-day operations. Finally, forest conservation programmes need robust financial backing to cover restoration, monitoring, research, and sustainable forest management costs. In his landmark book, *Stolen Forests* [45], Bangladeshi dendrophile Philip Gain emphasises the critical importance of forest conservation: "Forests are our mother stocks of species and seeds. We can plant trees, but we cannot create forests. It is very important that we try to save our last forests" (p. 186). Universities can play a significant role in advancing this process [6].

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Data availability Data availability: The authors declare that all data supporting this study are available within the paper and supporting references.

Declarations

Competing interests The authors declare no competing interests.

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