HUNGARIAN UNIVERSITY OF AGRICULTURE AND LIFE SCIENCES

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# STUDIES ON LICHEN CONSERVATION THREATS BY INTERDISCIPLINARY NATURAL AND SOCIAL SCIENCE RESEARCH IN KENYA

PhD Thesis of the PhD dissertation

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## BACKGROUND AND AIMS OF THE RESEARCH

Tropical forests are characterised by high levels of biodiversity, ranging from animals to plants. The East African region has a unique biodiversity hosted by the Great Rift Valley that runs from Mozambique through Tanzania and Kenya and ends in Ethiopia. Additionally, Kenya hosts a wide range of terrestrial tropical habitats, including mangrove and coastal forests, cloud forests and alpine vegetation found at high altitudes. The biodiversity is decreasing enormously over time due to changing climatic effects, habitat loss and other environmental changes (MITTERMEIER et al. 2003, 2004, 2011, VAN BREUGEL et al. 2015). The remaining rainforests, extensive arid woodlands and savannas still represent a considerable diversity in plants and animals (MITTERMEIER et al. 2011). Thus, the country is one of the most intensely investigated East African areas also for its abundant lichen vegetation (FARKAS and MUHORO 2022, FARKAS et al. 2023, KAASALAINEN et al. 2021a, b, 2022, 2023a, b, SWINSCOW and KROG 1988) with an estimation of 1,400 species by TASSILO FEUERER in 2011 (KIRIKA et al. 2012a).

The protection of biological and ecological diversity has been a policy and sustainability issue for some time, but cultural protection lags, even though they share many common factors that, when addressed together, point to a much better outcome. These include culturally relevant education and revitalisation programmes (PRETTY and PILGRIM 2008). In broad agreement with this, in order to gather appropriate knowledge, an interdisciplinary study is necessary, the natural science, ecological-botanical approach alone is not sufficient, but that a social science, social and cognitive anthropology approach is also needed, i.e., an approach that involves meeting and communicating with people combining the interface between lichen-biology/ecology and cultural anthropology.

There are a few ethnobotanical studies in Kenya (MUTHEE et al. 2011), where traditionally applied medicinal plants (for example with anthelmintic effect) are revealed (NANKAYA et al. 2020). In the field of ethnolichenology, researchers try to find indigenous knowledge on the traditional applications of lichens by humans (DEVKOTA et al. 2017, YANG et al. 2021, VINAYAKA and KEKUDA 2023) passed down through generations. Higher plants (herbs) and lichens have several such traditional applications (alleviating respiratory or gastrointestinal disorders), especially in medicine (GAKUYA et al. 2020). Therefore, lichens can be utilized in pharmaceutical products as raw materials (PEREIRA et al. 2020). The collection and preservation of ethnomycological and ethnolichenological data are supported by the initiative "Ethnomycological knowledge in Africa," through the 2021 database application EthnoMycAfrica, a repository for published data from recent peer-reviewed publications and books (KINGE et al. 2023).

Currently, most children are no longer interested in learning the practices of their ancestors, as is often hypothesized that traditional knowledge may not help them later in life, and thus traditions (less useful or even useful ones) are being lost at a fast rate (BELLINO 2018, GÓMEZ-BAGGETHUN 2022). A significant part of this knowledge loss is due to cultural modernization. Globalization has put pressure on people to integrate and adapt to the ways of other cultures. The youth of the society, not seeing much value in their traditional ways due to schooling and digital tools introduction, have dropped many traditions and absorbed the new culture (FERNÁNDEZ-LLAMAZARES et al. 2021). This has led to a gap in the knowledge of the traditional culture and a loss of valuable cultural assets. The knowledge transmission is a key to maintaining the culture and identity of a given community, which is characterized by its way of life and its heritage (HUNTINGTON 2018). Joining the elders and youth in participatory research related to their knowledge is an important step in reversing this trend, as it validates the knowledge of the youth and encourages them to assume the role of knowledge reservoirs (BELLINO 2018). Although there is substantial research on lichen diversity and threats caused by environmental changes in East Africa including Kenya, there is a gap between limited traditional knowledge on lichens and its passage to newer generations, especially their use and conservation measures compared to other regions. Most studies primarily focus on lichen diversity, taxonomy, habitat (FARKAS and MUHORO 2022, FARKAS et al. 2023, KAASALAINEN et al. 2021 a,b, 2022, 2023 a,b, SUIJA et al. 2018, SWINSCOW and KROG 1988), and composition (KIRIKA et al. 2018), while some citizens are rich in knowledge mostly acquired through direct contact with their environment.

Lichens are a self-sustaining mutualistic relationship between a mycobiont (fungi) and one or more extracellularly existing photobiont (algae or cyanobacteria) that also involves an indefinite number of microorganisms (HAWKSWORTH and GRUBE 2020). They colonise a wide range of substrates, including bark, rocks, and soil, leaves of trees and fronds of fern trees in the tropics or various anthropogenic substrates. They are abundant across diverse ecosystems, from polar tundra to tropical forests from sea level to high elevations in mountains well above the timberline or even tree line (KAASALAINEN et al. 2021a, AHTI et al. 1990). These organisms contribute to essential ecological processes such as microhabitat formation and primary succession (SUTAR et al. 2021). Additionally, lichens contribute significantly to ecosystem functioning (ZEDDA and RAMBOLD 2015, COZZOLINO et al., 2022; SCHEIDEGGER and STOFER, 2015).

Lichens are highly sensitive to environmental changes (INSAROV 2010, KULARATNE and DE FREITAS 2013). They absorb water directly from the air, making them susceptible to air pollution and climate change. As a result, they are globally used as bioindicators – their presence or absence reflects air quality, forest health, and even climate change impacts. Declines in lichen populations often warn of problems such as increased pollution or habitat degradation, emphasising their value in monitoring ecosystem health (AGNELLO et al. 2004, HAWKSWORTH et al. 2005).

They are crucial bioindicators of environmental pollution due to their physiological sensitivity (AGNELLO et al. 2004, ÇOBANOĞLU ÖZYIĞITOĞLU 2020). While vascular plants have tissues and organs for water uptake and other functions, the thalline structure of lichens allows the direct uptake of atmospheric air and water over the entire thallus surface, resulting in a direct interaction with air quality and various environmental factors (COZZOLINO et al. 2022).

Despite their resilience to desiccation and temperature extremes, lichens remain vulnerable to stressors. Their diversity in photobionts and the presence of secondary metabolites attribute to their survival and colonization on harsh environments such as deserts, polar regions or temperate semi-arid sandy grassland vegetation, which are scarcely occupied by other organisms (XU et al. 2020, FARKAS et al. 2024). The poikilohydric nature (PÉREZ-ORTEGA et al. 2012) makes them sensitive to climate change and human pressure, which calls for conserving their diverse species (PAOLI et al. 2019).

Lichen diversity in Kenya has been challenged by land fragmentation and land use change, substantial research, temperature and precipitation patterns affecting environmental changes in Kenyan ecosystems, in contrary to a wide range of ecosystems serving as lichen habitats (KAASALAINEN et al. 2021a, 2023a). Flowering plants have typically received priority in Kenya's diversity and conservation strategies, whereas lichen-forming fungi (and fungi in general) are rarely mentioned in national biodiversity action plans or reserve management guidelines (ACTS 2016). Land fragmentation and forest encroachment have greatly led to the reduction of lichen populations (GIORDANI et al. 2020). Many macrolichens thrive in old-growth forests and undisturbed ecosystems. Kenya's high-elevation forests (e.g., in the Aberdares, Mount Kenya, Mau complex, Taita Hills) have suffered fragmentation and reduction (MITTERMEIER et al. 2011, MYERS et al. 2000). Additionally, climate change is expected to alter temperature and precipitation patterns, affecting Kenya's ecosystems. Although detailed studies are lacking locally, these global climate-driven impacts are a concern for East African lichens (LAWRENCE et al. 2023, NAEKU 2020).

The most comprehensive treatment of the region's foliose and fruticose lichens is "Macrolichens of East Africa" by SWINSCOW & KROG (1988). This has given rise to advancement in lichenological research in Kenya (FRYDAY et al. 2022). New scientific techniques and approaches emerged that transformed the study of lichens. Molecular biology and DNA barcoding became available in the 2000s, allowing researchers to revisit and refine lichen classifications established by earlier mostly morphology-focused studies. Many Kenyan macrolichens identified in the 1980s have been re-examined with recent methods, leading to a concise species distinction (COCA et al. 2025, KIRIKA et al. 2015, 2016a, 2017a, 2019, 2022). Collaborations between Kenyan scientists and international specialists have led to taxonomic and floristic studies and descriptions of several new species using advanced methods in the western world, which is lacking in Kenya (FARKAS et al. 2023, FARKAS and MUHORO 2022, KAASALAINEN et al. 2023b, KIRIKA et al. 2012a, b, SUIJA et al. 2018).

Documenting lichen biodiversity is a critical step toward conservation planning, ecological monitoring, and sustainable land-use management (SCHEIDEGGER and GOWARD 2002, SCHEIDEGGER and WERTH 2009). The first published 1994 IUCN Categories and Criteria (IUCN 1994), following considerable research and international consultation, were developed to improve objectivity and transparency in assessing the conservation status of species globally and to enhance understanding among users. The "Guidelines for Using the IUCN Red List Categories and Criteria" are regularly updated, the current version is of 16 March 2024 (IUCN 2024). It states: "If a taxon is known, but there is no direct or indirect information about its status or possible threats, then it is obviously Data Deficient (DD). A Data Deficient listing does not imply that a taxon is not threatened" (IUCN 2024). Consequently, DD is not a threat category but indicates that more information is required to categorise the species in future. YAHR et al. (2024) emphasise the key role of population size and distribution in Red List category assessment. They establish that assessors are struggling with the availability of information about individual species. And this applies to several taxa of the world, and is highly true for lichens in Kenya. In Kenya, where habitat loss and fragmentation continue to threaten natural ecosystems, understanding their composition and distribution may provide early warnings of ecological degradation and offer essential data for biodiversity assessments.

## AIMS

Considering the above detailed knowledge, the following objectives were planned to be achieved:

1. to analyse literature on lichen conservation for evaluating global research trends on threats to lichens, and for identifying drivers of threats to lichens and their shifts over time, various levels of threat,

2. to compile the updated lichen checklist of Kenya,

3. to establish a conservation risk category system for lichens in Kenya,

4. to identify lichens from East-African collections,

5. to explore traditional knowledge on lichens and its importance in the conservation of lichens in Kenya,

6. to find solutions and suggest proposals for conserving and/or recovering lichens under threat.

## MATERIALS AND METHODS

A literature review was conducted using bibliometrics (VOSviewer and Biblioshiny) for analysis. It is a quantitative method that applies statistics to publication and citation data to map the evolutionary structure and the progress of a research field (BAKER et al. 2020). It not only ensures a systematic and transparent analysis, but also enables a replicable evaluation procedure based on the statistical measurement of science, scientists, and scientific activity (ARIA and CUCCURULLO 2017). Online bibliographic databases, such as Web of Science (WoS) and Scopus, are among the proposed sources of metadata concerning scientific works (COBO et al. 2011), as their corpus can be read by analysing software. The systematic flowchart of data search, screening and analysis was carried out according to PAGE et al. (2020). A comprehensive search was conducted across both Web of Science and Scopus databases using the string: ((("lichen*")) AND (("threat") OR ("decline")) A ND (("climate change") OR ("air pollution") OR ("direct human impact"))) (KANYUNGULU and FARKAS 2026). The timespan was restricted to 1981–2024. The bibliometric, biblioshiny R core team (2023) package was used to generate data output, including an overview of annual scientific production, document sources, authors' scientific output, country-specific scientific production, and the cumulative occurrence of themes.

The literature on annotated checklist was obtained from public online databases Google Scholar, Recent Literature on Lichens (RLL), Scopus, and Web of Science were used to search literature on Kenyan lichen records after SWINSCOW & KROG (1988). The following search words were used: ”Lichens in Kenya” in databases of more general topic, and “Kenya” and the time period adjusted to 1988 – 2024 in RLL to achieve as many papers as possible according to basic guidelines from recommendations, and proposed steps to follow when conducting a systematic search (KHAN et al. 2003). The distribution and habitat records summarised in the book “*Macrolichens of East Africa*” were the most crucial baseline for our research. We focused on updating its taxonomic nomenclature and new records of literature data published after 1988, since SWINSCOW & KROG (1988) had thoroughly examined the earlier literature sources for East African (including Kenyan) lichen records. Approximately 90 literature sources were surveyed, revealing the current occurrence of c. 725 lichen species (incl. 172 crustose microlichen species).

These publications were subjected to further analysis based on their contents. Articles highlighting crustose microlichens, including foliicolous lichens and lichenicolous fungi, papers focusing on lichens of other countries and merely mentioning their presence in Kenya (based on previous literature sources), and not containing records from Kenyan sites, were excluded from the research. The growth forms of lichens are most often characterised as fruticose (shrub-like), foliose (leaf-like) or crustose (crust-like) (HAWKSWORTH and HILL 1984), and lichens of fruticose and foliose lichen thalli generally referred as macrolichens, while crustose ones as microlichens. Though the order Caliciales was treated by SWINSCOW and KROG (1988), its representatives were largely categorised by us as microlichens and excluded from this treatment, since it is generally regarded as having crustose thalli with stalked (and mazediate) apothecia. However, from genera containing both crustose and squamulose species, the squamulose (as small foliose) ones were kept among macrolichens (e.g., a few representatives of the genus *Phyllopsora*).

Finally, altogether, 42 journal articles were found and used for further analysis on macrolichen species of Kenya. The macrolichen species from the 42 articles were listed in an Excel sheet with details on distribution data, substrate, and environmental tolerance factors were added. Annotation by distribution within Kenya was recorded where possible, East African countries were abbreviated similarly to Swinscow and Krog (1988): E (for Ethiopia), K (for Kenya), T (for Tanzania) and U (for Uganda), including also R (for Rwanda), and worldwide distribution data were also given if available. The year of collection was added if it differed significantly from the year of article publication. The nomenclature was updated using mycological databases, which are Index Fungorum (https://www.indexfungorum.org/names/names.asp) and Mycobank (https://www.mycobank.org/), to ensure a common nomenclatural basis for comparable data gained from various literature sources over about 30 years, when many taxonomic changes took place.

A traditional knowledge study was conducted from July to September 2023 in four major counties in Kenya out of the 47 counties in the country. The study areas are named after the counties Kakamega, Narok, Nairobi, and Makueni (1–4 respectively) as shown in Figure 1. The northern and eastern part due to geography, relief, climate and vegetation is regarded less rich in lichens, furthermore these areas have a lower population density.

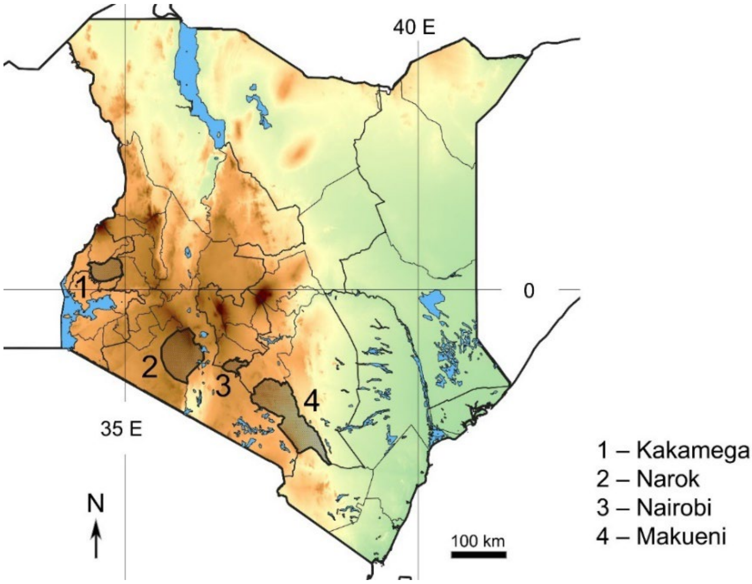


**Figure 1.** The geographical map of Kenya presenting the study areas within county boundaries (QGIS 3.36 'Maidenhead' 2024). Scale 100 km.

The field data-collecting methodology utilized semi-structured interviews that included both closed and open-ended questions. To achieve the quality of the study, the selected questions were discussed in collaboration with the Traditional Ecological Knowledge Research Group in the HUN-REN Centre of Ecological Research (Vácrátót) for pre-screening and approval before delivering them to the participants.

The study was geared toward understanding the relationship between age, literacy levels, traditional knowledge, and urbanization and how this affects basic biological and ecological knowledge on lichens and their application, furthermore conservation issues especially lichens in Kenya.

The morphology and anatomy of the lichen thalli were studied using a NIKON Eclipse/NiU (DIC, epifluorescence) compound microscope (Nikon Corporation, Tokyo, Japan), as well as a Nikon SMZ18 stereo microscope (Nikon Corporation, Tokyo, Japan). Micrographs were prepared using Nikon

DS-Fi3 camera (with NIS-Elements BR software, Nikon Corporation, Tokyo, Japan) with the above-mentioned microscope.

High-performance thin layer chromatography (HPTLC) analysis of lichen specimens for identification lichen secondary metabolites was carried out according to standard methods described by ARUP *et al.* (1993) and MOLNÁR and FARKAS (2011).

## RESULTS AND DISCUSSION

### Research focused on threats to lichens over time

According to the results of the bibliometric analysis (1981–2004), research on lichen threats was sparse but heavily centered on air quality and environmental pollution (KANYUNGULU and FARKAS 2026). "Air pollution" stands out as one of the main themes during these decades. The 1970s and 1980s witnessed a significant concern over acidic rain, industrial emissions, and their ecological effects (HAWKSWORTH 1971). Lichens, being extremely sensitive to sulfur dioxide and other pollutants, were widely used as an indicator of air pollution (CONTI and CECCHETTI 2001, PRADO et al.2025). The concerns of pollution led to standardised protocols for lichen monitoring in forest health and air pollution programs. A notable outcome was the integration of lichens into environmental policy – for example, lichens were included in European forest condition monitoring under the UNECE Air Convention from 1985 (FRATI and BRUNIALTI 2023, UNECE 2025a, b). In the 1990s–2000s, other pollution challenges emerged (e.g., the increase of nitrogen deposition), which kept the lichen–pollution theme relevant even as its research received somewhat less attention. Studies reported shifts in lichen communities due to nitrogen oxides and ammonia from agriculture and traffic, with increasing abundance of nitrophilous lichen species (e.g.; *Xanthoria parietina*) (GUTIÉRREZ-LARRUGA et al 2020).

Around 2005, the annual number of lichen-threat publications began to increase noticeably. Globally, the early 2000s resulted in new high-level commitments to combat climate change and biodiversity loss. For instance, the Kyoto Protocol (negotiated in 1997) entered into force in 2005, and the Convention on Biological Diversity had outlined ambitious targets for 2010 to reduce biodiversity loss (CALDWELL et al. 2024, UNFCCC 2025a). These initiatives emphasised climate impacts and species conservation as significant issues, expanding the scope and funding of research. The mid-to-late 2010s brought the landmark Paris Agreement (2015) (UNFCCC 2025b) on climate change and the start of climate advocacy, as well as key assessments of biodiversity loss. In addition, in the late 2010s, there was the integration of lichens into international conservation frameworks. Fungal specialists (including lichenologists) became organized under the IUCN Species Survival Commission to conduct Red List assessments for lichenized fungi, a process that was started after 2015.

**Geographic patterns of research output on threats to lichens**

The production of research on threats to lichens is uneven geographically. Certain countries and regions contribute unequally to the topic. Analysis of authors and publication origins indicates that temperate, developed countries in the Northern Hemisphere dominate this field. Europe and North America stand out as hotspots of lichen threat research, having main research centres developed in their universities and other institutions. Several factors help to explain this pattern: these regions have long traditions of lichenology and possess the institutional and financial support for sustained research programs (PRADO et al. 2025). The United States and Canada, for their part, have integrated lichen monitoring into national forest and air quality programs since the 1980s, resulting in a steady stream of data-rich studies (e.g, the USDA Forest Service lichen biomonitoring network in forests across the U.S. contributes to many publications) (MCCUNE et al. 1998, U.S. Forest Service (2025). In contrast, countries and regions in the Global South (e.g., tropical Asia, Africa, South America) are underrepresented in the bibliometric data on lichen threats. This is not necessarily due to a lack of threats – indeed, many of these regions host rich lichen floras that are likely experiencing pressure from deforestation, pollution, and climate change – but rather due to historically limited research capacity and funding in lichenology (FRYDAY et al. 2022).

This geographic disparity in publication output may also reflect differences in environmental priorities and funding: developed nations have been able to invest in long-term ecological monitoring (where lichens feature as indicators), whereas developing nations might prioritise other immediate conservation issues, with lichen-specific threats garnering less attention so far. This geographical pattern highlights a concentration of lichen conservation research in economically developed regions with established environmental science infrastructures and long-standing traditions in ecological monitoring (ZHAO and TAGHIZADEH-HESARY 2022, YAHR et al. 2024, AGARWAL 2025).

## Updated and annotated checklist of lichens in Kenya

Approximately 90 literature sources were surveyed from 1988 to 2024 (KANYUNGULU et al. 2026), following the first synthesis "*Macrolichens of East Africa*" by SWINSCOW and KROG (1988), revealing the current occurrence of 725 species (incl. 172 crustose microlichen species). Based on 42 journal publications and online sources used for analysis of the Kenyan lichen checklist, the current occurrence of approximately 209 previously known macrolichen species was confirmed. After the necessary nomenclatural revision, a checklist of 553 macrolichen taxa (including 5 varieties) was compiled. Thus, so far, 548 macrolichen species of 96 genera were recorded from Kenyan ecosystems. A conservation risk category system was established for Kenyan lichens and applied to 553 taxa of foliose and fruticose macrolichens.

**Species under Extreme Risk (in Kenya) [ER(K)]**

The 39 species (7%) listed in the category "*Species under Extreme Risk (in Kenya) [ER(K]*" are predominantly known from the time and place of original description, and the Kenyan type specimens (holotype, isotype, paratype) originate from several decades ago and dates back before 1988. It is a category that might contribute to the future identification of species belonging potentially to the IUCN category CR – Critically Endangered.

**Species under Significant Risk (in Kenya) [SR(K)]**

The 197 species and two varieties (36%) listed in the category "*Species under Significant Risk (in Kenya) [SR(K)]*" are rare in Kenya / rare in East-Africa, however, they have seldom a distribution record outside Africa. It is a category that might contribute to the future identification of species belonging potentially to the IUCN category EN – Endangered.

**Species under Medium Risk (in Kenya) [MR(K)]**

The 180 species and four varieties (33%) listed in the category "*Species under Medium Risk (in Kenya) [MR(K)]*" are mostly rare to fairly common or with old record(s) only, mostly collected before 2000 (prior to the beginning of molecular genetic research period). It is a category that might contribute to the future identification of species belonging potentially to the IUCN category VU – Vulnerable.

**Species under Low Risk (in Kenya) [LR(K)]**

The 77 species (14%) listed in the category "*Species under Low Risk (in Kenya) [LR(K)]*" are with relatively narrow distribution (usually not in all East African countries), scattered outside Africa / tropical zone, their habitats or documented localities are endangered potentially, thus threatened by the decrease of their populations soon. It is a category that might contribute to the future identification of species belonging potentially to the IUCN category NT – Near Threatened.

**Species under Negligible Risk (in Kenya) [NR(K)]**

The 54 species (10%) listed in the category "*Species under Negligible Risk (in Kenya) [NR(K)]*" are regarded common in Kenya, occur in several East-African countries and other continents and most often involved in molecular genetic studies based on freshly collected samples. It is a category that might contribute to the future identification of species belonging potentially to the IUCN category LC – Least Concern.

**Macrolichen species diversity in Kenya**

Lichen data from Kenya represent a broad taxonomic and ecological diversity across alpine rock surfaces, alpine and montane forests, dry savanna woodlands, and mangrove-lined coasts. High-altitude areas such as the Aberdare Mountains, Mt Elgon, Mt Kenya, and Kakamega Forest were identified as the most frequently visited areas (Figure 2) and parts of the Eastern Afromontane biodiversity hotspot (MYERS et al. 2000, MITTERMEIER et al. 2004, 2011, KIRIKA et al. 2018).

The composition of Kenya's macrolichen flora is unevenly spread across genera. Over half of the genera are represented by only a single species (e.g., *Anzia*, *Cetrelia*, *Gabura*), a few genera are exceptionally species-rich (*Parmotrema* – 64 species, *Hypotrachyna* – 38 species, *Usnea* – 34 species, *Xanthoparmelia* – 25 species, *Leptogium* and *Ramalina* – 24-24 species). Together, the top 10 genera (approximately 10% of all genera in the dataset) account for roughly 58% of all macrolichen species of the country.

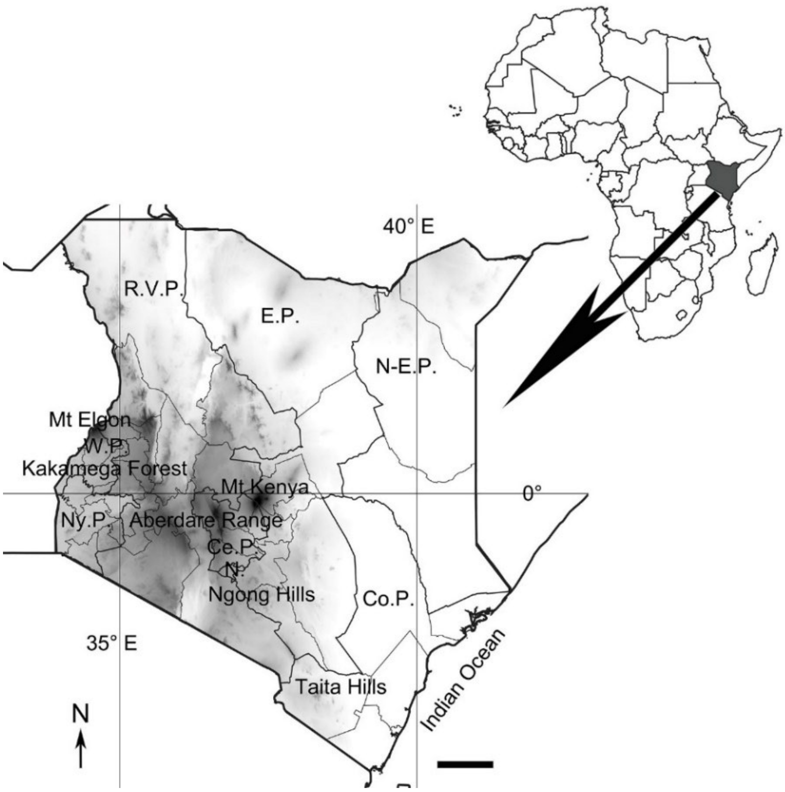


**Figure 2.** The geographical map of Kenya presenting the main areas, hotspots within province (until 2013) and county boundaries (QGIS 3.36 'Maidenhead' 2024). Provinces abbreviated: W.P. = Western, Ny.P. = Nyanza, R.V.P. = Rift Valley, Ce.P. = Central, N. = Nairobi, E.P. = Eastern, N-E.P. = North -Eastern, Co.P. = Coast. Scale bar: 100 km.

The composition of Kenya's macrolichen flora is unevenly spread across

**Conservation implications of the diverse macrolichen diversity**

The findings have important implications for conservation and biodiversity monitoring of Kenyan macrolichens. First, due to the vast diversity of macrolichens across Kenya's varied ecosystems conservation efforts must be equally diverse. An effective lichen conservation strategy should focus on habitat variety, ensuring that montane cloud forests, humid coastal forests, and drier woodlands all remain protected. Several macrolichens, especially foliose and fruticose types, like *Parmotrema* and *Usnea*, thrive in old-growth montane and coastal forests, while other genera (e.g., *Xanthoparmelia*) are adapted to open savanna or alpine habitats (KIRIKA et al. 2018). This means that conservation plans need to include multiple ecosystem types and not to focus solely on well-known forests (ANTÓN-PARDO 2019, POTT 2014).

The genus richness, diversity, and distribution carry important conservation implications (HAWKSWORTH and LÜCKING 2017). The great diversity among the macrolichen species that has been noticed emphasises how diverse Kenya's biodiversity is across a variety of environments (KIRIKA 2012 a,b, KIRIKA et al. 2018, LAWRENCE et al. 2023, NAEKU 2020). Not all genera are found in a single habitat; savannas, alpine zones, coastal woods, and montane forests all support a variety of taxa. As a result, an effective conservation strategy must prioritize lichen substrates throughout many ecosystems rather than concentrating on a single habitat type. Assessing the effects of policies (such as logging, land fragmentation, agriculture, grazing, and afforestation) on lichens is a necessary part of comprehensive management (BU et al. 2015, MITTERMEIER et al. 2011, PINNA et al. 2018, SCHEI et al. 2013). For example, to maintain full ecosystem function, tree species selection in reforestation should be emphasised for encouraging epiphyte colonisation. Similarly, grazing zones should be maintained to ensure minimal lichen disturbances.

## New distribution records from East-African lichen collections

82 specimens were identified from Kenyan and Tanzanian lichen collections (FARKAS et al. 2025). New records of Kenyan and Tanzanian specimens were identified, and data of 57 species are reported and evaluated, indicating

that even the relatively well known East African region is far from fully explored.

New distribution records were established for 57 lichen species in East Africa. Seven species: *Flavoparmelia pachydactyla* (Hale) Hale, *Hypogymnia subobscura* (Vain.) Poelt, *Hypotrachyna microblasta* (Vainio) Hale, *Montanelia disjuncta* (Erichsen) Divakar, A. Crespo, Wedin & Essl., *Parmotrema pilosum* (Stizenb.) Krog & Swinscow, *Usnea aristata* Mot. and *Xanthoparmelia phaeophana* (Stirton) Hale are new for Tanzania. *Hypogymnia subobscura* (Vainio) Poelt is a new distribution record also for East Africa.

## Traditional knowledge on lichens and their conservation

The semi-structured interviews conducted in 4 study areas in Kenya targeted the understanding of lichenology among Kenyan citizens. The citizens of these areas (both urban and rural) from different age groups were interviewed on their understanding of the biological nature and morphology of lichens, their habitats, their use and possible applications (KANYUNGULU and FARKAS 2025). Subsequently, conservation ways of nature and lichens were also discussed and if people thought lichens to be threatened, possible ways of conservation were also asked.

According to the demographic relations of the analysis, the results show that the young seem to have a limited knowledge of ecosystems compared to their older generation that have proficiency in the same. This might be brought about by the digital era, modernization, and changing literacy trends. Concentrating on recent, novel matters can result in the decline of traditional knowledge. Most of the knowledge is concentrated in the age groups 26–35 and 36–45 with the highest level in 26–35 years (Table 1).

Table 1. Knowledge of lichens across different age groups in Kenya in the numbers of respondents (n=60).

| **Knowledge of lichens** | **Age**<br>**18–25** | **26–35** | **36–45** | **46 and above** |
|---|---|---|---|---|
| None | 5 | 0 | 0 | 0 |
| Little | 7 | 7 | 4 | 3 |
| Medium | 3 | 8 | 6 | 3 |
| High | 0 | 8 | 5 | 1 |

The age group 46 and above recorded the lowest numbers as most of them were not willing to share their knowledge due to busy schedules and only one had proficient knowledge of lichens and conservation. Fortunately, their knowledge ranged from little to high with most of them having little to medium knowledge and no cases for lack of knowledge. This calls for integrating traditional and modern education in conserving both culture and the environment (HUNTINGTON 2018).

Medicinal use of beard lichens (e.g., *Usnea bornmuelleri*, Figure 3) was mentioned from Makueni county where the tradition still exists even in the past 2–3 decades. The thalli, collected from rock boulders, is ground into powder and mixed with tea or soup and the bitter liquid is taken against headaches. This effect of usnic acid, also present in the applied lichen, has been reported from *U. diffracta* (that contains also diffractaic acid) (NASH 2008, OKUYAMA et al. 1995) for analgesic effects.

Conservation is a way of protecting the treasures of a country including its living organisms. Responses collected represented effecting agents and the frequency of responses was expressed in the number of mentions regardless of the number of respondents (Threats to lichens in Table 2).


**Figure 3.** *Usnea bornmuelleri*, a lichen applied in tea against headache in Makueni study area, A, the habit of some thalli, B, a detail of a high performance thin layer chromatographic plate, used to identify lichen secondary metabolites from the thalli responsible for the alleviating effect. Scale 1 cm.

According to the results (Figure 4) setting laws that govern and penalties in case of breakage of any law, education on lichens, and conservation (NAEKU 2020) were proposed as leading factors to conservation gain. Two major bodies, Kenya Wildlife Services (KWS) and Kenya Forest Services (KFS), furthermore Forest ACTS 2016 having a role in conservation were mentioned by respondents. Habitat protection where species thrive attracts attention from the government and the community surrounding any conservation facility (game reserves, national parks, protected forests and sanctuaries) in Kenya termed as friends of the specific facilities.

The fact that a few people did not know about conservation, calls for attention to either the government of Kenya or ecologists to create a schedule for sensitizing its citizens and maybe include them in basic academic programs in schools (COCKERILL and HAGERMAN 2020). Kenya is a frequent target of tourism, and although much has been centralized on wildlife (mostly large

Table 2. The types of threats to lichens determined in different study areas by interviews of 60 respondents.

| | Threats to lichens | | | | | | |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | |
| Kakamega | 2 | 9 | 1 | 3 | 8 | 1 | |
| Narok | 5 | 2 | 0 | 2 | 1 | 0 | |
| Nairobi | 5 | 9 | 5 | 0 | 4 | 0 | |
| Makueni | 4 | 10 | 2 | 0 | 9 | 0 | |
| Total | 16 | 30 | 8 | 5 | 22 | 1 | 82 |
| Percentage | 20% | 37% | 10% | 6% | 27% | 1% | |

The number of mentions is given irrelevant to the number of respondents (n=82). Unaware of lichen threats (A), human factors (B) industrialisation (C), unprioritized conservation efforts (D), environmental factors (E), invasive species (F)

mammals) conservation, especially in savannas and forests, in their habitats formed by higher plants further small living organisms and geological formations are highly protected for their survival.

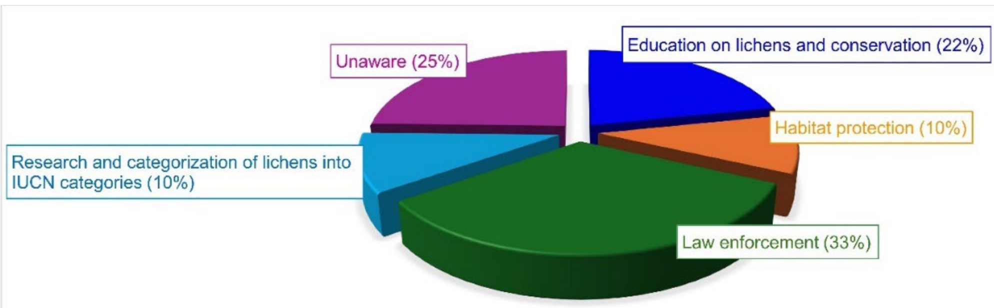


**Figure 4.** Knowledge on conservation-related matters of lichens.

## Proposed recovery measures of lichens from their threats

Tentative recovery measures were suggested as ways to sustain lichens globally in the environment. These are the following:

1) Species and habitat protection by law, increase awareness, monitoring of protected and invasive species and important habitats, developing management practices.

2) Establishing the vulnerability of species by IUCN categories.

3) Revision of IUCN categories and improvement of the management practice accordingly.
4) Improvement of status assessment of species and its application.
5) Protection of endangered areas rich in epiphytes and terricolous species-rich lowland areas.
6) Placement controlled industrialisation far from natural habitats and involvement of lichenologists in planning.
7) Translocation of populations and preservation of the quality of the adequate environment.
8) Implementing continuity-based substrate management to ensure the long-term availability of specific host trees

## CONCLUSIONS AND RECOMMENDATIONS

Lichenological studies show a gradual increase over the past three-four decades, as an answer to the global emphasis on biodiversity and climate change. Most of the studies are floristic works and taxonomic treatments, but research has also expanded to include lichens as bioindicators. The findings highlight potential areas of ecological interest and taxonomic complexity and may serve as a basis for biodiversity assessments, conservation planning, or further taxonomic revision. The diversity of genera like *Parmotrema* and *Hypotrachyna* warrants closer examination, while single-species genera present opportunities to explore rare or poorly known taxa. The category system – established here – can be extended to other geographical areas where a large amount of Data Deficient species are found. Further research is crucial in under-sampled regions and for understanding the impacts of environmental change. Collaboration among taxonomists, ecologists, and conservationists will be essential to advancing lichenological research and safeguarding Kenya's lichen heritage.

New records of Kenyan and Tanzanian species were identified and data of 57 species reported and evaluated, indicating that even the relatively well known East African region is far from fully explored. Seven species represent new distribution records for Tanzania. Additionally, *Hypogymnia subobscura* (Vainio) Poelt is a new distribution record for East Africa. Future field studies in countries of East Africa may result in a better knowledge of a wider distribution area of these and also other species.

Tentative recovery measures can be applied for the sustainable conservation of lichens. Effective responses highlighted for threats that cause lichen habitat loss through either pollution, climate change, or human impacts are the protection of critical habitats, maintenance of forest heterogeneity, reduction of anthropogenic disturbance, and systematic monitoring of invasive species (SCHEIDEGGER and GOWARD 2002, MUELLER et al 2022). National and regional strategies, such as establishing protected areas and adapting land-use policy, remain central to safeguarding lichen diversity (KUZEMKO et al 2016, NARAYAN et al 2023).

Beyond habitat-related pressures, the lichen thallus is directly affected by air pollution and heat and temperature stress from climate change effects, which can be mitigated through the involvement of lichenologists in industrialisation planning and the establishment of industrial facilities away from nature reserves (WEI et al 2020). Moreover, the bibliometric analysis outcome revealed two critical gaps. Firstly, collaboration remains limited, with only 23% of studies involving international co-authorship, suggesting that lichen research networks are still regionally centred. Secondly, there is a geographical imbalance in contributions: most publications come from North America, Europe, and parts of East Asia, while presumed biodiversity-rich regions such as Africa, South America, and Southeast Asia are underrepresented. To address these gaps, recent literature calls for stronger integration of lichens into global biodiversity policy, refinement of IUCN assessments from all regions, and international collaboration that includes underrepresented regions. Even if we consider that conservation and redlisting (understanding that redlisting is not equal to protection by law) are local matters, since state governments create their own laws and redlisting must be the prior responsibility of local experts, the following international cooperation still can be introduced or increased: creating and incorporating general ideas, theories, contributing in identification of lichen taxa, selecting methods used in monitoring, restauration, applying instruments better available in more developed countries, adding that less developed areas should also do their best for increasing their knowledge and struggle for increasing governmental research budget for the necessary innovations. Such multidimensional and inclusive efforts are critical to ensuring the persistence of lichens in rapidly changing environments (LÜCKING et al 2020).

The study of traditional knowledge shows a diverse pattern of knowledge by the various age groups, and literacy levels from urban and rural study areas and confirms evidence of unused local knowledge, traditions and applications among the Kenyan communities, which are rapidly being eroded by modernisation and the development of academic knowledge. In order to prove the viability of a concept acquired in traditional knowledge, laboratory analysis should be involved as a recent possibility originating from modern education. Traditional knowledge must be documented, and its transmission to younger generations through oral or in many other ways cannot be postponed. In addition to making the research and data collection process more effective, introducing a multi-disciplinary approach, the involvement of cultural anthropology (action anthropology) and its mediating role can also be of great help in this. However, to conserve lichen biodiversity in Kenyan hotspots, traditional and academic knowledge should be integrated. In addition, updating practical knowledge incorporated into the framework of formal education and coordinated with one's own environment can also be a forward-looking solution. The role of lichens should be better explained in regular education, and the awareness of the elderly needs to be increased and motivated. Furthermore, informing communities about alternative sources and energy can also be an effective solution, they should be sensitized on alternative sources of energy as most are over-collecting and destroying several tree species in the form of firewood, in extended rural areas, where forest trees represent substrate (bark and wood) for epiphytic lichens.

## NEW SCIENTIFIC RESULTS

1. An updated checklist of Kenya – consisting of 172 crustose and 553 foliose and fruticose taxa, altogether 725 taxa of lichen-forming and lichenicolous fungi – was compiled.

2. A conservation risk category system was established for Kenyan lichens and applied to 553 taxa (548 species and 5 varieties) of foliose and fruticose macrolichens.

3. New distribution records were established for 57 lichen species in East Africa. Seven species: *Flavoparmelia pachydactyla* (Hale) Hale, *Hypogymnia subobscura* (Vain.) Poelt, *Hypotrachyna microblasta* (Vainio) Hale, *Montanelia disjuncta* (Erichsen) Divakar, A. Crespo, Wedin & Essl., *Parmotrema pilosum* (Stizenb.) Krog & Swinscow, *Usnea aristata* Mot. and *Xanthoparmelia phaeophana* (Stirton) Hale are new for Tanzania. *Hypogymnia subobscura* (Vainio) Poelt is a new distribution record also for East Africa.

4. Evidence originating from Kenyan communities in Kakamega, Narok, Nairobi, and Makueni reveals a significant reservoir of unused local knowledge and traditions. While these applications remain culturally relevant, findings indicate they are undergoing rapid erosion due to the dual pressures of modernisation and the prioritisation of formal academic knowledge.

5. The study established that nature conservation capacity is independent of formal literacy levels; instead, it is driven by a combination of traditional and educational knowledge. Data revealed that non-literate respondents possessed substantial conservation expertise required to be transferred to the younger generations.

## LIST OF PUBLICATIONS SUPPORTING THE THESIS RESEARCH

### Published papers in peer reviewed journals

**KANYUNGULU, C. N**. & FARKAS, E. É. (2025): Awareness of Lichens and the Necessity of Their Conservation Among Citizens in Different Regions of Kenya. In: *Acta Botanica Hungarica*. 67(4): https://doi.org/10.1556/034.2025.00573.

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### Conference presentations related to the thesis

**KANYUNGULU C. N.** & FARKAS, E. (2023)The importance of lichens and their conservation [A zuzmók és természetvédelmük jelentősége]. *Acta biologica plantarum agriensis* 11(2): 30.

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