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Perspective

The importance of a transformative biodiversity education for perceiving, appreciating and supporting lichen diversity in German urban environments

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Abstract

Urban green spaces are indispensable for the conservation of biodiversity in Germany. In addition, the availability of green areas often provides citizens with the only opportunity to experience nature. Lichens are an important component of urban environments in terms of both species diversity, and ecosystem functions and services. However, they are rarely the subject of biodiversity education. To bolster awareness on their diversity and appreciation, a transformative biodiversity education in both the formal and informal sectors is necessary. This transformative biodiversity education should not only provide knowledge about species and habitats, but also on all dimensions of biodiversity, viz., the three levels of biodiversity, drivers of biodiversity loss, and ecosystem services. For this reason, the design of biodiversity education may be particularly challenging for educators and teachers. This paper shows how biodiversity education projects on urban lichens can be developed in accordance with the principles of transformative education, supporting nature experience, knowledge transfer (species knowledge in a broad sense and interdisciplinary aspects), participation and cooperation, as well as the use of digital media. Two best-case projects, tested in Germany, are presented as examples for the design and implementation of a transformative lichen education in urban areas. A similar approach can be easily applied in other education systems beyond national boundaries.

Keywords: awareness raising; cities; ecosystem services; nature conservation; sustainability

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Introduction

Nature in German urban areas

A third of the world's population lives in urban areas today, and this number is expected to increase in the future. With more than 83.1 million inhabitants (in 2021) and 238 people per km^2 (in 2020), Germany is one of the most densely populated countries in the EU. In 2021, around 78% of the total population lived in cities (Statistisches Bundesamt 2022; World Bank–Data 2022). The need for healthy living conditions and for a good quality of life in an urban living, working and leisure environment is, therefore, a growing priority (Kowarik *et al.* 2017).

Cities are a patchwork of buildings, streets, green and fallow areas, urban trees as well as remnants of old cultural and natural landscapes. Despite such a high concentration of people and the strong influence of humans in urban areas, cities in Germany are often more species- and habitat-rich than the surrounding agricultural and forest landscapes.

Here, habitat loss and fragmentation caused by intensive land and forest use, as well as pollution from nitrogen and pesticides, have a hugely deleterious impact on biodiversity. Furthermore, the urban climate is warmer than in the surrounding areas, and so cities provide good habitats for warmth-loving species, such as exotic Mediterranean species. Various habitat types are found even in small spaces, most of which are created and shaped by anthropogenic activities. These are important replacement habitats for numerous species, even for those rare and endangered, which have become scarce in the countryside. Protected areas can also be found, but these are mostly of small size and are fragmented, and not always accessible for nature experiences (Lude 2010; Kowarik 2011; BMU 2019; UrbanNBS-Team 2020).

Nature also provides so-called ecosystem services in cities. For example, green spaces and urban trees contribute to lower temperatures on hot days, thanks to evaporation and shading. Plants produce oxygen and bind CO_2. Other positive effects are related to the improvement of air quality (trees filter dust and can reduce particulate matter pollution by between 5 and 10%). Nature contributes to climate protection and to climate change adaptation. It has a positive effect on human well-being and quality of life. For this reason, it is essential to raise awareness of nature (Kowarik 2011; Kowarik *et al.* 2017; UrbanNBS–Team 2020).

Lichens in urban areas in Germany

Lichens are an important component of urban environments in terms of both species diversity, and ecosystem functions and services, and colonize both natural and artificial substrata. However,

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they are often overlooked and neglected in nature conservation, landscape planning, and biodiversity education. Citizens have a very poor knowledge of lichens and are mostly unaware of their diversity and importance. Lichens are frequently regarded as non-living unaesthetic patterns, or even as being harmful for buildings or trees, and are actively removed or destroyed (Wirth & Kirschbaum 2014). In contrast to the species poverty of the last century caused by air pollution from acidic emissions, the diversity of urban lichens has become richer in the past few decades and numerous species are now spreading in German towns. Not only does the decrease in sulphur dioxide pollution cause this, but also the eutrophication of habitats and global climate warming (Windisch 2016). Under the influence of the currently dominant eutrophic emissions with nitrogen compounds, caused in particular by traffic, there has been a shift in favour of *Xanthoria*- and *Physcia*-dominated epiphyte communities (Wirth *et al.* 2013; Llewellyn *et al.* 2020).

To give a measure of lichen species richness in German urban areas: 310 species are known from Berlin (Krause *et al.* 2017), where at an old cemetery alone, 72 lichen species were recorded on trees, gravestones and walls by Buchholz *et al.* (2016). Approximately 351 lichen species occur in Hamburg (Feuerer & Schulz 2014). A total of 500 lichen species have been reported from the Ruhr metropolitan region, one of the largest in Germany (Keil *et al.* 2021). In the smaller Bonn/Rhein-Sieg region, more than 200 lichen species growing on different substrata have been recorded so far according to Mutke *et al.* (2019).

Similar to other organisms, lichens provide numerous ecosystem services and functions even in urban environments. For example, they support the diversity of other organisms, water retention during rainfall, the reduction of carbon dioxide in the atmosphere, climate adaptation and improvement of the microclimate. Lichens protect soil from erosion and support the immobilization and detoxification of metal and radionuclide pollutants in the soil. Furthermore, lichens can be used as bioindicators of air quality, and can inspire artists with their typical colour patches on stones, tree trunks and buildings (Zedda & Rambold 2015).

The most important threats to lichen populations are emissions and eutrophication, as well as active destruction of lichen thalli, lichen substrata and habitats (Stapper & Kricke 2004). While conservation measures for lichens are often practised in forests and in other natural habitats, lichens are rarely supported in cities. Therefore, it is important to improve the knowledge and awareness of lichens through adequate and targeted education.

Trends in biodiversity education

The failure of numerous nature protection measures in recent decades has shown that more than nature protection alone, sustainable activities are increasingly important for maintaining and supporting biodiversity (Wittmer *et al.* 2021). Education is regarded as critical for promoting sustainable development and improving the capacity to address environmental and developmental issues in society. It supports nature conservation efforts and is recognized as the key to transforming the relationship with nature and encouraging environmental responsibility (Lude 2010; Wittmer *et al.* 2021).

Environmental Education (EE) became particularly important in the 1970s; it focused mainly on environmental issues and aimed at supporting environmental literacy. However, EE lacks interdisciplinarity and has been considered unhelpful in stopping biodiversity loss (Navarro-Perez & Tidball 2012). During the last 30 years, EE has evolved into new education forms such as Education for Sustainable Development (ESD). ESD connects environmental issues with economic and social aspects, with an orientation towards competencies and learning outcomes. The aim of ESD is to achieve a sustainable development of society. Important components of ESD are, among others, ethical, temporal (orientation towards a sustainable future, planning in a proactive way, and considering the consequences of action or non-action), and cross-disciplinary (interrelatedness and interdisciplinary thinking) (Transfer-21 Programme 2007; Lude 2010; Navarro-Perez & Tidball 2012; Filho *et al.* 2016). Educational principles include systemic thinking, problem solving, values orientation, co-operation, focus on participation and action, self-organization and holistic perception. This concept stands for the ability to contribute to and shape the future (Lude 2010). However, ESD has been criticized by some authors for being based on ethical, cultural and conceptual issues, mainly with an anthropocentric view, which does not help bridge the gap between people and nature (Navarro-Perez & Tidball 2012). In addition, sustainable development has a homogenizing and moralizing tendency that does not give space to self-determination, autonomy and alternative ways of thinking (Navarro-Perez & Tidball 2012; Dittmer & Gebhard 2021).

Biodiversity education shares common goals with EE (to gain awareness of and sensibility to the environment) and ESD (interdisciplinarity, understanding of drivers for biodiversity loss, participation and collaboration, systemic thinking etc.). Nevertheless, biodiversity is a more complex concept, having different multidimensional aspects, for instance, the three levels of biodiversity (gene, species and ecosystem), the dimension of ecosystem functions and of ecosystem services, and the link to human well-being, cultural aspects, the economy and social justice. In addition, it is important to consider biodiversity not only at the global, but also at the regional and national levels (Navarro-Perez & Tidball 2012).

For the implementation of the recently agreed Global Biodiversity Framework (CBD/COP/15/L.25 2022), a transformative, innovative and transdisciplinary education with formal and informal educational programmes, at all levels is, in particular, regarded as an essential tool for achieving behavioural change and for promoting sustainable lifestyles and biodiversity values. Transformative learning is a potentially important aspect in encouraging learners to move beyond the simple acquisition of knowledge to a deeper and more holistic learning experience, which has the potential to change the way people understand and conceptualize their world (Walshe & Sund 2022). Transformational learning approaches align well with participatory, place-based and enquiry-based pedagogies, which are inherently student-centred; they include a range of strategies, as well as critical pedagogies, which generate a questioning frame of mind, a reflective approach to our actions and the actions of others, and a commitment to do something. This holistic approach to transformational learning experiences focuses on involving students' heads (engage), hearts (enable) and hands (enact), to inspire and cultivate critical thinking, relational knowledge and practical applications (Bourn & Soysal 2021; Walshe & Sund 2022).

According to Dittmer & Gebhard (2021), education needs a plurality of perspectives: space for free experience and creativity. The development of a positive emotional bond with nature is the basic prerequisite for a later commitment to the concerns of nature conservation and environmental protection. A modern education approach should combine knowledge transfer with

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concrete experiences of nature involving all the senses (Louv 2010; Gebhard 2013; BMU 2019). Nature experience is, therefore, an important element of biodiversity education for achieving awareness on and acceptance of biodiversity, as well as for supporting transformation.

Owing to the complexity of the topic 'biodiversity', the design and practical application of a biodiversity education going beyond EE can become very challenging for educators. The present work intends to help educators and teachers by giving some advice on how such projects can be designed and realized in a practical manner, taking lichen diversity as an example. Based on the experience of the author in this field and on recent literature, the following components are considered particularly relevant for biodiversity education and are therefore introduced below in greater detail.

Nature experience. One of the important elements of transformational learning theory is the emotional property. Outdoor activities are considered very important for developing awareness related to the environment and for reconnecting to nature (Uyanik 2016; Dittmer & Gebhard 2021). During nature experience, nature is not only objectively grasped with scientific categories, but it is also charged with manifold personal subjective meanings. People, especially children, are emotionally touched by a phenomenon, positively or negatively. This opens up space for fantasy, imagination and alternative ways of seeing and acting. Reflection takes place as well as the exchange of views and opinions. Consequently, the ability to think and reflect as well as language skills are strongly promoted (Dittmer & Gebhard 2021).

Knowledge transfer. Knowledge of nature alone does not have much effect on individual environmental behaviour: the phenomenon of 'knowledge behaviour gap' is well known in education science (Navarro-Perez & Tidball 2012; Moormann *et al.* 2021). Biodiversity is about more than organisms and their ecosystems; it also considers needs for food security, medicines, fresh air, shelter, and a clean and healthy environment (Lude 2010; Taratsa 2010). Biodiversity education involves several disciplines (geography, politics, business, civil society, nature conservation, etc.) and has links with topics of current importance, such as climate change, health and social equality (Lude 2010; Taratsa 2010). Therefore, interdisciplinarity and the outline of relationships between biodiversity and other issues is of outstanding importance in education. Species knowledge is not merely the knowledge of a species name and species identification traits; it is also about biological, ecological, cultural, and/or social aspects (ecosystem services). Species knowledge should be more a holistic concept in the sense of species literacy, a means to open up the world, or to transform the relationship of the self to the world, and so is an important component of an educational process (Hense 2021).

Participation and cooperation. Participation is understood as participating in, and influencing, decisions and developments that affect one's own life, as well as participating in the results of these decisions, viz. in the fields of action and on goods that are important for living (Goudarzi *et al.* 2021). The possibility of participation in nature means both influencing such decision-making processes and using natural spaces for recreation and experience. According to approaches of democracy building, it is preferable that children and youths have participatory experiences as early as possible and as often as possible, especially if they belong to disadvantaged societal groups. In nature education, participation opportunities should always be offered, for example, through reflection and discussion (Goudarzi *et al.* 2021), and planning and acting together with others (cooperation), in line with ESD. These provide motivation to become active and can motivate others to also get active. Nature issues are not limited to the training of species specialists; rather, they concern the entire population.

Use of digital media. Skills in computer application and information sciences are very important in improving professional career opportunities and to participate in society. The use of digital media can support biodiversity education in different ways (Schreiber & Siege 2016). It is particularly useful for young people, as they can be introduced to nature more easily. The acquisition of knowledge can even increase when compared to traditional education. Digital media also promotes greater individual participation and motivation, the opportunity to make decisions for oneself, the joy of playing, and social interaction. However, there is also criticism regarding the use of digital technologies by young people, since this may increase the time spent on screens. Their application is, therefore, not recommended for children, but first for teenagers. There are many ways of using digital media, from geocaching or games in nature, to interactive identification of taxa (Dotterweich & Lude 2021). Tools such as identification apps are a serious means of support in recording biodiversity (citizen science) and can be used easily, even by non-specialists. Regardless of how reliably such apps work, a certain amount of background knowledge and user involvement is always essential (Simmel *et al.* 2022). In addition, digital media offer the chance to record otherwise inaccessible information and signals using, for instance, sensors and infrared cameras. They also possess a high potential for improving accessibility and inclusion, and for supporting creativity (Dotterweich & Lude 2021).

Training in lichenology as part of biodiversity education also requires a transformation to improve knowledge on, and promote awareness of, lichens and their appreciation in order to contrast lichen diversity loss. The present paper outlines how biodiversity education can be improved in urban areas in accordance with the principles of a transformative education. Experiences gathered with different target groups in Germany, within the formal and informal learning system, are being used to exemplify how new insights and general aspects related to nature-based education can be put into practice. A particular aim of the present paper is to show how lichens can be embedded into such projects. A similar approach can be easily applied in other education systems beyond national boundaries. Practical best case examples for two projects designed and tested by the author are presented and analyzed in line with the criteria illustrated above.

Material and Methods

Numerous education projects concerning lichens in urban areas of Germany have been designed and implemented by the author of this paper in the period 2011–2022. These included children, youths, students and adults as target groups. The projects took place in the context of school and out-of-school environmental education, in cooperation with non-profit organizations, schools, and a national history museum. They can be summarized as follows:

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- Projects on lichens as bioindicators of air pollution at secondary schools in Berlin and Bonn in Italian and English language (4 × 3-day projects; age of students 16–18 years)
- Projects on lichens and their diversity for schools within the project *TaxonomieWerkstatt* at the Zoological Research Museum Alexander Koenig (ZFMK) in Bonn (several 2-hour appointments with classes and their biology teacher; age of students 11–13 years), and lichen excursions with a permanent Saturday group of children in Bonn (several 4-hour appointments; age of students 11–13 years)
- A project on lichens and their diversity, including lichen identification, for young people of the *Deutscher Jugendbund für Naturbeobachtung* (DJN) e.V. in Sankt Augustin (2-day project; age of participants 18–27 years)
- Excursions to explore the urban wild nature of Bonn with adults (2 × 3-hour events + 1-hour excursion) as part of the project '*Urban Wilderness – Biodiversity and Education for Sustainable Development*' with young people and adults.

In the conceptual phases and during implementation of the listed projects, attention was paid to the inclusion of the following components: nature experience, multidimensional knowledge transfer, participation and cooperation, as well as the use of digital media.

For all projects, information on lichens had been collected and teaching material prepared prior to the listed events. These included, among others, images of the most common lichens found on different substrata and simple identification keys. Based on this experience, this paper presents two examples of best practice projects on lichens, each including several actions. These can be carried out with children, young people and adults who are not familiar with lichens, within formal or informal, non-academic education. The 'Background information' given below is intended as a support for educators/teachers, who can potentially implement the proposed projects. Expert lichenologists can simply ignore this information.

Best Practice Project Examples for Lichen Education in Urban Environments

General aspects for both projects:

- **Target groups.** Children (at least 10 years old), young people, adults with limited knowledge of lichens (difficulty level to be scaled and adapted to target group).
- **Where?** Outdoors in a green area with trees, paths, asphalt, walls and buildings (e.g. in a school playground, a cemetery, or a park).
- **Learning material.** Pictures of lichens, for instance, of single species (e.g. *Lecanora muralis* (Schreb.) Rabenh.) or illustrations of different colours and growth forms of urban lichens (these are previously selected by the educator and colour printed or saved in digital form on a device); a magnifying glass; paper to write on and pens/pencils; eventually, smartphones or tablets.
- **Description.** Before starting outdoor activities, a teacher or educator gives a short introduction (around 5–10 minutes) on lichens. They first pose the question 'What is a lichen?' to break the ice and encourage a first discussion; they explain further, if necessary. With the help of the learning material, participants are invited to observe lichens in the surrounding environment. The exploration of lichens should be free, not guided by an educator, who is available only for questions and support, if needed. Enough time should be given to participants for an initial observation. Once lichens are found, practical activities can be carried out, as described below. During the different actions, the educator can provide targeted background information on particular features of the species (symbiosis, growth forms, colours or uses), as well as general information on lichens and their growth substrata, in order to kindle interest and to motivate participants. Not all the suggested actions have to be carried out during one appointment or with the same sequence. How many actions are implemented depends on the time available for each event.

Project 1: Where do lichens occur and how diverse are they?

Action 1: The variety of substrata on which you can find lichens

Background information. In urban areas, lichens colonize both natural and artificial substrata. Many rock lichens will also colonise artificial substrata, such as walls, boundaries, tombstones, concrete, mortar, asphalt, roofs and metal objects. Such anthropogenic substrata allow lichens to spread into rock-free areas. Other species are found on trees and shrubs, wood, mosses, and soil/humus.

Tasks and activities. On which substrata can you find lichens? Observe the environment and write about the substrata on which lichens grow.

Action 2: Lichen growth forms

Background information. Lichens are separated into three main types, in accordance with their growth forms. These are foliose, fruticose and crustose. Crustose lichens are similar to crusts, as the entire thallus is tightly attached to the substratum and can hardly be removed from it. Foliose lichens are leaf-like, grow mainly horizontally, are only partly attached to the substratum, and have well-distinguished lower and upper sides of the thallus. They usually present marginal lobes of various shapes, sizes and orientations. Fruticose lichens grow three dimensionally, are more or less branched, pendent from the substratum, or shrubby (only a very small part is attached to the substratum), with round or flat, sometimes hair-like branches. In addition, there are many intermediate forms between these three types. Lichen growth form is a response to environmental conditions and is related to the physiology and activity of lichens. Relationships have been detected, for example, with the nutrient uptake, photosynthetic performance, or water use strategy. In several studies, authors have observed that crustose and foliose forms, especially small foliose, are more tolerant of aridity than fruticose lichens which need higher air humidity to survive.

Tasks and activities. Do you notice any differences in lichen types and growth forms? What could be the reason for such a variety of growth forms? Take pictures of the different forms. Work together in small groups and discuss your results with the other teams.

Action 3: The variety of lichen colours

Background information. The variety of lichen colours (e.g. whitish, pale green, yellow, brown, grey, blackish) is related to the presence of coloured substances called pigments in the lichen cortex, an outer layer of cells formed by the fungal partner. The function

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of this layer and the pigments is to protect the photosynthesizing symbiotic partner (photobiont) from intense sun radiation (for instance, brown pigments). The concentration (and colour intensity) of some pigments may, therefore, vary from shaded to well-lit habitats (as an example, the orange-yellow *Xanthoria parietina* (L.) Th. Fr. can be shown to participants). When wet, lichens can even change their colour (i.e. become greener). The presence of green algae or cyanobacteria (blue-green/blue-grey) as photobiont can also influence the colour of the thallus. Other compounds have antimicrobial properties and protect lichens from harmful microbes.

Tasks and activities. Do you notice any differences in lichen colours, even within one species? What could be the reason for such a variety of colours? Wet a lichen with water and observe what happens. Take pictures of the different colour patches with your smartphone. Work together in small groups and discuss your results with the other teams.

Action 4: Lichen graffiti

Background information. The subject 'lichen' is linked to the arts topic 'graffiti'. This action can be performed indoors using participant's own pictures of lichen patches previously taken in the field, or outdoors, preferably painting on paperboard or canvas. Only if permitted, graffiti can be painted directly on a wall, for example, a boring grey wall of a school building, if uninhabited by lichen. Cooperation with an artist or an art educator may be established to introduce participants to the different graffiti techniques. Alternatively, images of lichen patterns can be elaborated digitally using an image elaboration software to create participant's own artwork, which could be exhibited in school or in other public rooms.

Tasks and activities. Lichen patches on walls or concrete often resemble graffiti. Take pictures, let the lichens and their patches inspire you, and paint your own graffiti on paperboard, canvas, the wall or digitally.

Project 2: Discover a common lichen in urban areas (Lecanora muralis)

Action 1: Detect the chewing gum lichen on paving stones and asphalt

Background information. *Lecanora muralis* is a crustose lichen forming regular rosettes with marginal squamules, and has a diameter of up to 10 cm. Crustose lichens are intimately associated with the substratum and usually cannot be easily separated from it. This is also the case for *L. muralis*, the thallus of which consists of rosettes that lie close to the substratum. These often have narrow, flat to slightly concave, marginal lobes. Very old specimens die inside and then form ring-shaped thalli, within which new, smaller thalli can develop again. *Lecanora muralis* often looks similar to chewing gum that has been spat out, giving rise to its English name 'chewing gum lichen'. *Lecanora muralis* was designated lichen of the year 2021 ('Flechte des Jahres 2021') by the BLAM Association (Bryologisch-lichenologische Arbeitsgemeinschaft für Mitteleuropa).

Tasks and activities. Observe the small whitish grey to pale brown patterns on paving stones and asphalt along sidewalks and streets. Which pattern is a lichen (*L. muralis*) and which one is chewing gum? Take pictures of all the patterns you investigate.

Action 2: Where does L. muralis *grow?*

Background information. *Lecanora muralis* is very common on different substrata. The specific epithet '*muralis*' comes from the Latin, meaning 'growing on the wall', as the species is found mostly on stony material (rocks, pebbles, etc.) in natural habitats, and on walls, fence posts, roof tiles, on pavements or even on asphalt in urban areas. Less frequently, it grows on wood or bark. The species prefers calcareous and/or dust-impregnated/nutrient-rich substrata (viz., fertilized bird perches), well-illuminated sites, and is tolerant of pollutants. The increasing warming and drought periods that are expected to occur even more often in the future do not harm this very drought-resistant species. It is even resistant to trampling and water inundation. Hence, *L. muralis* is found frequently in our towns. As a result of its toxicity tolerance, it is also used in the biomonitoring of trace metals.

Tasks and activities. Observe different substrata (stones, asphalt, walls, paths, trees, etc.) and look for *L. muralis* thalli. Where can you find this species and on which substrata is it more frequently found? Is the species common, and why so, in your opinion?

Action 3: Variety within L. muralis *(genetic diversity)*

Background information. *Lecanora muralis* is extremely variable in its shape and colours, and can be subdivided into several varieties. It is likely that the populations on natural rocks belong to a different ecotype to those found in cities. The variety of its colours ranges from white and dirty grey to pale brown. Thalli turn to green when wet. Fruiting bodies are brownish, round, and have a diameter of *c.* 1.5 mm.

Tasks and activities. Observe how variable the forms, colours and sizes of the different lichen thalli of *L. muralis* are. Take pictures of the different forms and colour patterns. What could the brown spots on the thalli be? What could the reason be for such a variety of thalli? Work together in small groups and discuss your results with the other teams.

Action 4: Estimating the age of a lichen thallus

Background information. Crustose species are the slowest growing of all lichens, particularly in dry environmental conditions. Like most rock lichens, *L. muralis* also grows very slowly, reaching an increase in radius of 1–3 mm per year, depending on the nutrient supply which is usually good in cities. Larger individuals can, therefore, have great longevity. However, the fact that individual thalli may fuse together to form much larger thalli should also be considered. In this case, the resultant thalli are not as old as expected, based on their growth rates. As a result of their slow growth and longevity, crustose lichens are used by earth scientists and archaeologists to estimate the exposure age of stone surfaces. This discipline is called lichenometry.

Tasks and activities. Find a large thallus of *L. muralis*, for instance on stone or on a wall. How old could it be? Measure the thallus diameter with a ruler and consider that it can grow radially only 1–3 mm per year (on average).

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Projects 1 and 2: Discussions on lichen importance

A final discussion can be stimulated within all projects or actions to support the ability of participants to think and reflect, and to promote action and problem-solving skills.

Background information. Lichens are often regarded in urban environments as non-living unaesthetic patterns, or even as harmful for buildings or trees in gardens and parks. For this reason, citizens actively remove them mechanically or chemically. However, lichens mostly do not cause any damage to the substratum on which they grow. On the contrary, thanks to lichen thalli, the dead surfaces of stony and artificial materials become biologically active and can capture sunlight, bind CO_2, and release oxygen, with positive effects for the environment. In addition, lichens support water retention during rainfall; water is released slowly into the environment and does not get lost in the canalization. This also contrasts with the fast percolation of rainwater in cities related to increasing urban sprawl and cementification, especially by heavy rainfall events under climate change conditions. Rainwater retention contributes to climate change adaptation and improves the microclimate in urban environments, particularly in hot summers.

Key questions to be discussed. Why are lichens important for urban environments? Which anthropogenic activities can disturb them? Should lichens be removed from their substrata of growth? How would you convince neighbours and friends to let lichens grow in their gardens and on their buildings?

Sources of background information for both projects. Aragon *et al.* (2019), Armstrong & Bradwell (2010), BLAM (2021), Ryan *et al.* (2005), Wirth & Kirschbaum (2014), Wirth *et al.* (2013), Zedda & Rambold (2015).

Discussion

The best practice examples presented above are intended for nature educators and teachers. These examples may support the development of other education projects on single lichen species or communities by following a similar approach and criteria, in Germany as well as in other countries worldwide.

The two projects are in line with the criteria for a transformative biodiversity education. Both projects support nature experience and direct observation of habitats and species outdoors, so that participants can immediately become active after a short input of knowledge. Green areas not only become the subject of education, but also a space where people can explore and experience nature, and learn about it. Urban biodiversity is extremely important, as cities are often the only place where citizens can encounter nature, especially socially disadvantaged groups (Kowarik 2011). Adequate, biodiversity-rich, easily accessible and suitable outdoor areas should, therefore, be available for different target and age groups. For children and young people, in particular, who have become increasingly alienated and distanced from nature in the past few decades, direct experience of nature and playing in a natural environment are very important for physical and mental development and for promoting an interest in nature. Personal responsibility, creativity, social behaviour and motor skills are strengthened through nature experience. Direct contact with nature also promotes understanding of the interrelationships between nature and the environment, which is indispensable for developing awareness of nature in all age groups (Louv 2010; Gebhard 2013; Kowarik *et al.* 2017; BMU 2019). Older children and young people have been shown to learn about nature through investigation and analysis, while younger children explore nature through play and movement. Practical activities in nature conservation, such as observation of useful plants and urban gardening, contribute to bringing citizens closer to nature and supporting nature appreciation and social integration (BMU 2019). The ability to think and to reflect is supported by group discussion. Enough time should be planned for activities and the observation of species and habitats, as recommended by education specialists (Dittmer & Gebhard 2021; Simmel *et al.* 2022).

Knowledge transfer is an important element of both projects. Short knowledge inputs are given about lichens as well as on interdisciplinary aspects (viz., urban planning, air pollution, climate change and culture). Lichen species knowledge is not limited to species names, but includes ecological, morphological and chemical aspects, and also information on lichen ecosystem services (viz., uses, aesthetics, etc.). According to different experts, excursions for young people and non-specialists, where only the teacher/educator speaks and provides the scientific and popular names of species occurring in a given area, should be avoided. Naming of the organisms can be a starting point (Hense 2021) but must be followed by imparting knowledge of complex interrelations and connections, and by nature experience activities (Lude 2010). The different aspects of biodiversity to be addressed in education should include the object (e.g. species, habitats), the benefits of biodiversity, and the relationship to ethics, culture, and/or other issues relevant to the future such as climate change, consumption, and individual behaviour (Lude 2010). According to Hense (2021), a regularly repeated 5-minute input on biodiversity, in combination with nature experience, can be sufficient to increase species knowledge and awareness in 10–12-year-old pupils. Knowledge inputs should be short and restricted to the most interesting aspects, especially for young people and non-specialists, in order to keep interest and motivation alive.

Species knowledge can only be practised by contact with the corresponding living creatures, and by those who have enough time for their own observation. However, in the current educational system in Germany, there is hardly time for such an in-depth understanding. A tendency to neglect accuracy in observations has been increasingly observed (Simmel *et al.* 2022). Identification of species is only recommended for older target groups, having at least some biological background knowledge and practice. According to Simmel *et al.* (2022), identification keys are composed of three essential elements: 1) specific technical vocabulary for naming relevant traits, 2) exact queries for the expression of traits (colour, length, numerical values, etc.), and 3) estimates for the expression of traits. These elements must be understood by participants, and cannot be applied without previous learning and practice. The availability of easy identification keys is, therefore, particularly important for a first attempt at lichen identification.

Both projects also support participation and cooperation. Participants are motivated to work and discuss issues in teams. Results and personal ideas are presented to the group. This supports their ability to plan and act jointly (teamwork), to solve problems and to communicate with others.

The use of digital media is supported by both projects, for example, by digital photography and image elaboration. Within other projects, with older target groups who already have a biological background, computer-aided identification tools can also

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be used. However, previous tutorials on lichen morphology, anatomy, chemistry, and taxonomy are necessary, as mentioned above. In recent years, several lichen identification tools have been developed in Italy (Martellos & Nimis 2008; Nimis & Martellos 2020). In Germany, while lichen interactive identification keys, including most of the species found in the country, are available via the LIAS light portal for scientists and experienced amateurs (Rambold *et al.* 2001), simple computer-aided tools (online and as applications for mobile devices) in the German language are still not widely available, especially those with a focus on urban environments. Very few simplified lichen identification keys for beginners in the German language are available for epiphytic lichens. These have been developed within the EU project KeyToNature-Dryades (https://dryades.units.it) (Nimis *et al.* 2012). Only a small number of websites (e.g. https://www.digital-nature.de/pflanzenwelt/flechten/flechten.html and https://botanik-bochum.de/pflanzenbilder_flechten.htm) offer the opportunity to identify a selection of lichen species by image alone.

As seen in other education projects on plants that have been designed and implemented by the author of this paper for youths and adults, AI-supported plant identification apps, such as *FloraIncognita* (https://floraincognita.com/) or *Naturblick* (https://naturblick.museumfuernaturkunde.berlin/), are excellent tools for making participants active during nature exploration. *Naturblick* has been developed specially for the urban nature of Berlin and includes identification aids for plants and animals, but not for lichens. With both apps, photographs of plants taken by participants are identified using an automatic image recognition process. Unfortunately, such tools are still missing for lichens but would be very useful for an introduction to lichen identification during nature exploration.

Conclusions

In order to combat the rapidly progressing biodiversity endangerment and extinction situation, it is essential to awaken and promote interest in biodiversity among the public, especially through broad-based and transformative education programmes. A connection with nature can only be fostered through direct experience, and the progressive alienation from nature in society can only be countered through appropriate education. Nature in cities is available right outside the front door, and is the closest and easiest place for citizens to experience it.

Owing to their importance and increasing diversity in towns, lichens play an important role in urban ecosystems and should be addressed more frequently in biodiversity education. However, lichen excursions and training in Germany mainly take place outside cities (i.e. in protected areas) and are targeted mostly at adults who have a certain background in lichenology, or at least in biology. Very few learning opportunities are offered to amateurs, children and young people.

As a conclusion, a transformative biodiversity (and lichen) education should promote:

- Nature experience and direct observation of habitats and species to support motivation, action, and reflection, allowing citizens sufficient time for observation;
- Knowledge transfer, not only of lichen names, but also on peculiarities of species (tell stories on single species as in the case of *L. muralis*), on habitats colonized by lichens, on the importance of lichens for other organisms and on their benefits (ecosystem services). To support an awareness and appreciation of lichen diversity, lichen topics should be linked to other topics such as culture (arts, photography, ethics, aesthetics, etc.), land use, air pollution and climate change;
- Participation and collaboration among participants, together with discussions on relevant issues;
- Experience with digital media, in particular for older target groups.

Learning opportunities should be diversified and their content and methods adapted to the different target groups. In addition, appropriate, freely accessible learning materials (including interactive identification keys and AI-supported identification apps) in German, with a focus on urban nature, need to be developed.

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